Approaches to Long-term Forecasting of Urban Water Demand in China

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Abstract

Forecasting long-term urban water demand is very important in water resources planning and management. In particular, faced with the threat of urban water scarcity, strategies and policies are required, and these need to be based on reliable water demand forecasts. However, there are many problems involved in forecasting long-term water demand, such as limited knowledge about the relationship between water use and the factors affecting it, uncertainties over the future and assumptions employed, the availability of water use data, etc. In China, little effort has been devoted to water demand forecasting, although water resources planning has been widely undertaken, and urban water shortage is currently a serious problem. In the light of the above, an overall approach to forecasting long-term urban water demand forecasting in China was undertaken.

After reviewing the literature, the Chinese urban water demand system was analysed systematically, in terms of the four water use sectors: residential, industrial, agricultural and commercial. Based on the results revealed by the analyses, a system dynamic simulation model was built for forecasting long-term urban water demand. A case study has also been carried out to apply the model and to evaluate its performance.

Compared to static models that have been developed in the literature, the system dynamic simulation model that has been developed in this study is superior in terms of the following aspects: (1) it clearly takes the time variable into account; (2) the system dynamic model allows alternative forecasts to be obtained easily and explicitly; and (3) the step-by-step procedures used in the system dynamic simulation give explicit and clear statements about the changing processes of the explanatory variables rather than simply accepting them as inputs.

Chapter One
INTRODUCTION

1.1 MOTIVATION

Urban water scarcity is ubiquitous in China. About three-hundred Chinese cities, which form over two-thirds of the total, are facing a water shortage problem. Although water supplies are limited, and the nation-wide water economization movement has been reported to be successful, urban water demands in China are growing rapidly owing to economic development, the growth of urban population, and a rise in living standards. Thus, in addition to continuously encouraging people to save water, many new water supply facilities will be required to be developed in the coming years to meet the increasing demands for water; and a massive river diversion from the Yangtze River to the North China Plain is even under discussion (Postel, 1992, p44).

Before constructing water supply facilities, forecasting future water demand is necessary and essential for deciding the size of projects and investments. Water supply facilities have a relatively long-life, and last for as long as 20, 30, 50, or even over a 100 years. Moreover, the construction of water facilities takes a long time, usually several years or even decades. The benefits of better long-term water demand forecasting arise from the avoidance of under- or over-investment. An example given by Herrington (OECD, 1987, p40) shows the dramatic waste of capital resources due to investment being made too early. On the other hand, if under-investment occurs, the problem of water shortage will become unavoidable. As pointed out by the US Senate Select Committee on National Water Resources:

> "Where cities do run out of water, the difficulty in most instances, up to now has been not so much a shortage of water as a shortage of vision ... what is required in most instances is not more water as such but more

> forethought as to future needs and possibilities and the willingness to finance preparation of plans and the provision of the additional waterworks needed to bring the water to the people." (Grima, 1972, p8)

This statement was made with respect to the American situation in 1960. After more than thirty years of development, and especially in an era when sustainable development is stressed, it may be argued that today's water scarcity, in many cases, is not only a problem of finance, but a problem limited by the capacity of natural environments or ecosystems. Water shortage occurs when the amount of water required exceeds the capacity of natural water supply at some particular time and place. For example, the serious water shortage which currently occurs in many large northern cities of China, such as Beijing, Tianjin, Qingdao and Darlian, should be seen as much as a problem of the environment as one of finance. However, it may be argued that if today's water shortage had been forecasted twenty years ago, efforts could have been made to prevent its occurrence, and today's situation would have been very different. Thus, from this point of view, this situation can also be regarded as a failure of forecasting or the lack of forethought.

In addition to utility development, water resources planning is also based on water demand forecasting. When the author was a member of staff of Lanzhou University in China, she participated in several research teams in investigating regional water resources planning. The common objective of these research projects was to formulate guide-lines for rational development of regional water resources, which were required by the central government. According to a document, titled "Outline for the Research of Rational Utilization and Demand-Supply Analysis of Water Resources in China" issued by the Ministry of Water Conservancy and Power in 1982, water resources planning is generally composed of three major parts: (1) the physical content and characteristics of water resources, including water distribution in subregions and in different seasons, annual hydrological fluctuation, and exploitable quantities; (2) the current water resources development situation, including the description of water used by sectors of industry, agriculture, residential, etc; and (3) forecasting and planning future water uses, which is mainly composed of strategies or proposals made for the development of water resources in order to meet the projected water needs (usually in ten or twenty years).

From these working experiences, it is obvious that forecasting water demand is the most difficult and fragile part of water resources planning. Future water demands in China are merely estimated by pure intuitive judgement, or by using a simple extrapolation of past trends. The strategies formulated in the plan are mainly based on forecasts of water demands and the quantities of natural water resources available. It is quite clear that the value of the plan will be diminished if the forecast upon which it is made is not accurate. Thus, water demand forecasting plays a very important role in water resources planning.

Forecasting, according to Armstrong (1978, p6), is concerned with determining what the future will look like, and planning is concerned with what the future should look like. A plan must identify what the world will look like without intervention, and also what the world will be like if different assumptions are made about the future, and what the world will look like if planning intervention occurs. These are the jobs of forecasting. The forecast is an input into the planning model (Viathionathan, et al., 1980). Forecasting will be present, explicitly or implicitly, whenever planning, of virtually any kind, is undertaken (Gardiner and Herrington, 1986, p7-16). Many plans fail because of poor forecasts. Forecasting may be seen as an attempt to make planning more informed, more rational, or even more scientific (Encel, et. al., 1976). Although forecasting faces a lot of risks and uncertainties, as pointed out by Prasifka (1988, p62), attempts at forecasting must be made if planners are to have some role in managing the future rather than just witnessing its arrival.

Although water demand forecasting is important, there has not been as much effort devoted to forecasting as that devoted to planning, due to the risks, uncertainties, and difficulties that forecast faces, long-term forecasting in particular. A number of theoretical and practical questions in water demand forecasting have not been completely answered, such as the impact of changing social, economic, political, and technological circumstances upon water demand, the relationship between disaggregation and the accuracy of forecasts, how to deal with uncertainties in forecasting, etc. Methods that have been developed and employed in water demand forecasting have various restrictions or limitations. Furthermore, it has been suggested that the accuracy of the forecast, and the reliability of forecasting models, varies from one set of data to another, from one time period to another, and from one place to another. In the light of the above discussion, this study investigates urban water demand forecasting with respect to the Chinese situation.

1.2 BACKGROUND IN BRIEF

1.2.1 Historical Development of Water Demand Forecasting

Forecasting water use, compared with water using activities, does not have a long history (Boland, 1985). People who live on water that is drawn directly from wells, springs, or rivers do not think about their future water needs. They have little concern about how much water they are using at any time, because they treat water as an infinite resource. Many of the early developed water supply systems were investor-owned systems serving a portion of an urban area: the area served depended upon the capability of the source. Since there was no obligation to supply water to the entire population, present or future, there was no need to forecast the demand which any particular population could impose (Boland, 1985).

Water demand forecasting becomes necessary only with the increasing obligation to supply water to all the residences, population and businesses in an area, and after the capacity of public water supply systems has developed sufficiently, or after they have the ability to increase their capacity to meet the present and future needs. In the United States, for instance, the rebuilding and industrialization of northern cities after the Civil War was accompanied by the construction of thousands of new water systems, mostly intended to serve all the local residents and businesses and even to provide for anticipated future population. From that time, a new element was introduced to water supply planning: that the quantity of water supplied should be determined by the needs of the population, not the capability of the source (Boland, 1985).

Another factor which drew attention to the need to forecast water demand, came from the pressure of urban water shortages which appeared in some countries during the last three or four decades. The shortage of water was thought to be caused partly by the lack of forecasting. People came to realize the importance of sound forecasts from failures to meet water demands in the past.

Forecasting water demand first became a useful tool for the management of public water supply systems about one hundred years ago in the United States (Boland, 1985). The Seattle (Washington) Water Department, for example, has been involved in forecasting water demand for more than eighty years (Dekay, 1985). Since then, as outlined in Chapter 2, methods used in forecasting have developed from the simple to the complicated, and from the subjective to the objective, with most of the methodological development being carried out in America.

In China, forecasting water demand started to attract more attention with research on regional water resources planning, especially after the end of 1970's. The forecasts made, usually large-scale and long-term, mainly served in formulating regional economic development plans. Research on river basin-wide, and province-wide water resources planning over the country was mainly carried out in late 1970's and early 1980's. Later, from 1983 to 1987, the research scale in water resources planning began to concentrate on urban areas, particularly the capital cities of provinces, partly necessitated by the occurrence of urban water scarcity. The methods used in forecasting were mainly simple extrapolation, single regression, and subjective judgements.

Forecasting urban water use was also made, some-what crudely, by local water supply companies in some Chinese cities, as a guide for developing their water supply capacity. However, most local water supply companies have not yet developed sufficient capacity to supply enough water to meet total urban water needs within their areas. For example, in aggregate, only 86.6% of the country's total urban population was served by a public water supply system in 1987 (The State Statistical Bureau of China, 1987a); and it was estimated that supply was about 10 million cubic metres per day less than what was demanded in the Chinese urban areas. This excess demand over supply was curtailed by restricting water use, albeit at times in undesirable ways, such as closing factories during peak times of water demand. Under these conditions, comparatively very little effort has been devoted to the long-term forecasting of urban water demand by the water companies themselves; with water companies instead concentrating on the allocation of water between alternative uses and rationing issues.

Faced with these serious urban water shortages, the Minister of Urban and Country Construction and Environment Conservation of China, Lin Hanxiong, pointed out: a solution can only be found by a sound long-term water demand forecasting approach (People's Daily, 20th July 1990).

1.2.2 Definition Declaration

To understand the contents of the thesis clearly, it is necessary to provide definitions of the key words used.

(1) Forecast

A forecast is a conditional statement about the future. It is about what is expected to happen if various assumptions turn out to be valid. There are both objective and subjective components involved in forecasting. The objective component consists of explaining past levels and patterns, while the subjective component is the application of the resultant knowledge to the future (Boland, 1985; Jones, et al., 1984; Prasifka, 1988).

There are several terms which are similar, but do not have exactly the same meaning as the word 'forecast'. 'Prediction' is used in more general ways than 'forecast'. Prediction is a statement about the future, whether conditional or not. So, forecasts may be regarded as predictions, but not all predictions are forecasts. The word 'extrapolation' is commonly used in a special method of forecasting, based on the assumption that past trends will continue into the future. Many forecasts rely on a set of assumptions which include the continuation of at least some past trends and/or relationships. Such forecasts are called 'projections' (Boland, 1985). In terms of the forecasting method employed, the 'projection' definition of forecasting is adopted in this thesis.

(2) Water demand

Water demand is defined, in this thesis, as the quantity of water required or needed by various water users or customers.

In the literature, a distinction is often made between 'water demand' and 'water requirement' (Prasifka, 1988; Jones, et al., 1984; Baumann and Crews, 1985), or between 'water demand' and 'water use' (Kindler, 1984, p150). Water demand is regarded as an economic concept or an analytical concept, which necessarily includes the price of water as an explicit explanatory variable. Water requirement or water use on the contrary refers to the quantity of water desired or consumed by the customers; these are descriptive concepts, not necessarily related to water price as an explanatory variable.

In this research, water price has not been employed as an explanatory variable in the forecasting model developed, because of the unknown relationship between water price and various water uses in the Chinese urban water demand system. Thus, water demand, water requirement, and water use, are used synonymously in this thesis, without implying any distinction, except in the Literature Review where various work on the subject are described.

(3) Long-term

'Long-term' usually implies the time during which significant structural changes occur (Encel, et al., 1976). In different disciplines, the distinction between 'short-term', 'medium-term', and 'long-term' differ. In meteorology, for example, 'short-term' may mean only two or three days ahead, whilst 'medium' may refer to a few months, and 'long-term' may extend to the next year. In economics, 'short-term' means a few months, perhaps as much as a year, 'medium' usually refers to the next five years, and everything after that is 'long-term' (Land and Schneider, 1987, p115).

In water demand forecasting, 'long-term' generally refers to a period during which new sources of supply and new facilities might be called for (Prasifka, 1988, p63). However, when it is used by different researchers, 'long-term' does not necessarily refer to exactly the same period of time, although the variation is not as notable as that used in different disciplines. The following definitions of 'long-term' have been used in water demand studies:

(1) Long-term: ten years or more (Kindler, 1984, p229).

(2) Long-term future: perhaps up to 50 years ahead although a 15 to 30 years horizon is more common (OECD, 1987, p5).

(3) Short-term: 1 to 2 years; medium-term: a time horizon which extends to some 10 to 15 years; long-term: stretching out to 30 years (Smith, 1986).

(4) Near future: 1 to 5 years; middle-run: 5 to 10 years; and long-term: 10 to 20 years (Xie, Rosso, et al., 1989).

Thus, 10 years is the minimum value usually set out in any 'long-term' horizon employed in water demand forecasting. The maximum value of the horizon should obviously be related to the credibility or reliability of forecasts, which may depend on the forecasting model adopted. When the simulation model developed in Chapter Ten is applied to the case study as described in Chapter Eleven, it is recognized that the standard error of forecast increases with the time horizon, but that it is thought to be acceptable within a 30 year period. Therefore, in this research, 'long-term' generally refers to a time horizon of between 10 to 30 years.

1.3 OBJECTIVES OF THE RESEARCH

The aim of this research is to find a more appropriate, more convincing, and more scientific way of forecasting long-term urban water demand, which is applicable to Chinese cities where long historical water use records are not often available. This is all the more important because the methods of extrapolation and a single coefficient regression to produce one single forecast for a future date, which are commonly used in China, have been recognised as being unreliable for long-term forecasting when significant structural changes are likely to occur, and especially in situations where long-term historical records are unavailable. Subjective methods, which are also commonly used in China, raise too many doubts to convince other people, decision-makers in particular, that the forecasts are acceptable, due to the implicit nature of the assumptions employed.

The hypothesis behind this study is that certain causal relationships exist between water uses and some factors, or variables, which can be employed in projecting water demand into the future.

This research aim requires an overall approach to water demand forecasting. The three procedures which have been adopted are in line with the three objectives, as listed below:

(1) Literature review: to understand what has been undertaken and what is in current practice in this field as a whole, and to understand the advantages and disadvantages of the forecasting methods that have been developed and used in the literature.

(2) Chinese urban water use system analysis: to understand the Chinese urban water use system, including the patterns of urban water use, and the causal relationships between water use and some factors, from a long-term perspective.

(3) Model building: to build a model or to develop some procedures which can be adopted in forecasting long-term urban water demand in China, based on the literature study and system analysis, and especially based on causal relationships, if such relationships can be established.

It may be argued that this research adopts a broad approach rather than concentrating on a special forecasting method. The model developed, however, is specialised, and results from the overall research. This kind of research is necessary and essential for approaching long-term urban water demand forecasting in China, because no systematic research like that undertaken here has been completed in China.

1.4 ORGANIZATION OF THE THESIS

The thesis is structured into twelve chapters. Except for the Introduction, Literature Review, and Conclusion, in Chapter 1, Chapter 2, and Chapter 12 respectively, the remainder is divided into two major parts, namely Part I and Part II. Part I, which consists of six chapters (Chapters 3-8), focuses on the analysis of the Chinese urban water use system. Part II, which consists of chapters 9-11, focuses on model building.

Chapter 2, titled as Literature Review, reviews the literature on water demand forecasting, mainly from the perspective of methodology and techniques.

In Part I, Chapter 3 is an introduction to the Chinese urban water use system, including the history of its development, management status, and the problems it faces today. From Chapter 4 to Chapter 7, the causal relationship between water use and the factors affecting it are separately presented for a variety of water using sectors: residential, industrial, agricultural, and commercial. Both quantitative and qualitative methods are used in these analyses. Because the factors concerned in the analyses are merely predictors, some relevant policies are recognized as the real major causes of change in these factors and in water use. In Chapter 8, the general background to major Chinese policies that have important influences on urban water demand, including population policy, regional economic development policy and urban policy are described.

In Part II, a system dynamic simulation model is developed and described. Chapter 9 is on the methodology of this model, including its conceptual structure, the mathematical deductive process from the single coefficient method to the introduction of system dynamic simulation, and the consideration of uncertainty and alternative futures in forecasting. In Chapter 10, a system dynamic simulation model is presented. It is composed of four subroutines corresponding to the four water use sectors analysed. In Chapter 11, a case study applying the system dynamic simulation techniques is modelled, and the performance of the model is evaluated.

In Chapter 12, the conclusions drawn from this research are presented, including the findings from the Chinese urban water demand system analysis and from the model building and case study, and suggestions for further research are recommended.

Chapter Two
WATER DEMAND FORECASTING: LITERATURE REVIEW

2.1 FORECASTING METHODS

Many different approaches have been used or proposed for water use forecasting. Gardiner and Herrington (1986, p9-11) suggest three main types of forecast:

(1). Judgemental forecasts;

(2). Extrapolative forecasts; and

(3). Causal forecasts.

Boland (1985), Baumann (Baumann and Crews, 1985), Dekay (1985), and Prasifka (1988) classify the forecasting methods in more detail. They classify the Causal forecasts into Single Coefficient methods and Multiple Coefficient methods, which are treated as parallel to Judgemental and Extrapolative methods. See Table: 2-1.

The approaches to different methods, according to Boland's classification, are reviewed in the following sections.

Table 2-1 Water Use Forecasting Approaches

Consensual Methods	
	Simple judgement
	Collective judgement
	Structured judgement (e.g, Delphi methods)
Time Extrapolation	
	Simple extrapolation
	Time series analysis
	Other time extrapolation
Single Coefficient Methods	
	Per capita requirements
	Per connection requirements
	Unit use coefficient approaches
Multiple Coefficient Methods	
	Requirement models
	Econometric demand models

Source: Boland, 1985.

2.1.1 The Judgemental Methods

The judgemental forecast is based on personal or group knowledge: it may be purely subjective or merely an adjustment of a more formal forecast (McDonald and Kay, 1988). It makes no attempt to explain present or future water use, avoids explicit explanation, and focuses on pure prediction (Boland, 1985; Prasifka, 1988, p73). It is a method of time-saving, money-saving and without facing the restriction of data limitation. Objective content, therefore, is minimal and little can be said of the reliability of such methods (Boland, 1985).

The judgemental method is used to some degree from time to time and from one user to another, and is used to combine with other methods under many situations as well. A major reason for making modifications to the objective results derived from other approaches is that future trends may be different from past patterns. The Seattle Water Department, for example, occasionally uses the judgemental methods which rely on experience to project growth rates of total system water demand, or to postulate a relationship between water use and a specific variable that may not be determinable by statistical analysis (Dekay, 1985). The Gompertz Growth Curve(1) model used by Wang Bin, et al. (1990, 1991), for another example, is needed to give, or judge, the value of the upper limit of the asymptote.

Judgements are always made with desires or developmental objectives. Sometimes, it is difficult to distinguish judgemental forecasts from supposed targets. In one Chinese city's water resources planning (Jinchang city in Gansu Province), for instance, although the present residential water use is 182 litres per person per day (referred as lpd hereafter), it is suggested that residential water use in the year 2000 be only 120 lpd. This is in consideration of the availability of local water resources; and a forecast of water use is made by multiplying the per capita water use with the projected population. The explanation for the declining per capita water use is that the current per capita water use in the city is higher than in the neighbouring areas, where water resources is limited, the current water shortage is serious, and the potential growth of future population and industrial production is unavoidable. Therefore in this case, the reduction of the per capita water use is the only choice (Yang, Peng and Qiao, 1990). Most of the forecasts made by the Chinese water supply companies during the past few years were similar to this. The Chinese regional water resources plans made in late 1970's and early 1980's, sometimes also raised confusions about their forecast-whether it is a forecast or a planned target?

(1) Gompertz Curve. A growth curve that has the shape of a nonsym-meterical S-curve. It can be stated as

$$\log Y = \log l + kG^t$$

where Y is the dependent variable, l is the upper asymptote, k is a coefficient to be estimated, G is the growth expressed as constant ratio per unit of time, and t represents time. (Armstrong, 1978, p481)

Prasifka (1988) pointed out that all forecasting relies, to some extent, on subjective judgement, but its role in the forecast ought to be appropriate and explicit.

2.1.2 Extrapolative Methods

Extrapolative methods rest on the notion that changes in water use can be explained by the passage of time (Boland, 1985). These methods relate future water use only to past levels of water use. No other variables are considered in the analysis. (Dekay, 1985). Therefore, they are the least data-intensive of all models and relatively easy to use.

There are many ways to do the extrapolation. It may be simple or complicated; may be accomplished by graphical or mathematical means; and the change over time may be treated as linear, exponential, or logistic, or as conforming to some other functional relationships (Prasifka, 1988). An example of a very simple method is to regress the quantity of water use (total, sectoral, or per unit) with the time variable t (year) (Li and Liu, 1989). A more complicated model, for example, is the adoption of the Gompertz Curve (Wang Bin, et al., 1990); while another one is to combine the simple regression model with a Markov Chain (Ding H., 1990). Models have even based on spectral expansion by orthogonal functions of past data (Sterling and Antcliffe, 1974). One of the most commonly used extrapolative methods is the time-series, in which the Box-Jenkins or ARIMA (AutoRegressive Integrated Moving Average) model is the most commonly applied (Chen Y., 1988; Quevedo, et al., 1988).

It is questionable to assume that the trend in the past will be continued in the future. Thus, the extrapolation method is suspected not to give accurate prediction beyond a few years (Boland, 1985; McDonald and Kay, 1988). George (1985) cites two major disadvantages with time-series models, which may be applicable to other extrapolative methods:

(1) they are not useful as policy tools, and they are inaccurate when significant changes in determining variables occur in the future; and
(2) they can be quite sensitive to their starting values, which carry the greatest weight in the forecast.

Extrapolation is a useful method for some short-term forecasting applications, especially in on-line water supply network management (Perry, 1981). A research contributed by Miaou (1986) introduces other variables, like temperature and precipitation, in the time-series analysis to forecast daily urban water use. In long-term water demand forecasting, extrapolative methods are used, in some cases as a baseline forecast combined with or adjusted by other forecasting methods (Dekay, 1985). It is also used as a convenient alternative forecast or one of the scenarios in practice (Niu, 1986).

To a certain extent, like the subjective judgement, extrapolative methods are used to some degree in all forecasting. This is because the experience of the past is the only basis for forecasting. The causal forecast methods, for example, rely on the relationship conducted from the past experience, or records. And it may be argued that this is, in fact, to "extrapolate" this relationship into the future.

2.1.3 The Single Coefficient Methods

The single coefficient methods employ a single explanatory variable. The most commonly used variables are population and service connections, although any factor affecting water use can be used (Prasifka, 1988).

A general mathematical model of the single coefficient methods may be summarized in the following simple form:

$$Q = cX + e \tag{2.1}$$

in which Q is the quantity of water used or demand in a time period; c is the water per unit use (per capita, per connection, or other unit thing); X is the explanatory variable; and e is the error term, or residual, with an expected value of zero.

In reality, the above theoretical linear equation can be expressed in exponential, logistic, or other convertible forms.

According to the explanatory variable chosen, the single coefficient methods can be classified into three categories: per capita coefficient, per connection coefficient, and unit use coefficient methods.

Per Capita Coefficient

Of all single coefficient methods, the per capita approach is by far the most widely used (Prasifka, 1988; Jones, et al., 1984; and Baumann and Crews, 1985). This approach estimates future water use by multiplying expected future population by a projected water use coefficient. Although population may be projected by various means, it is usually obtained from other professional forecasting or with some adjustments. The per capita coefficient may be taken as fixed over time, or it may be projected to change with time. Its value and (where applicable) its rate of change may be determined from past water use pattern in the same area, in similar areas, for the whole region, or for the nation. Alternatively, the coefficient value may be obtained from reference works or from other studies, or it may simply be assumed (Prasifka, 1988).

The per capita method requires relatively little data, and the data are easily obtained. It is widely used for forecasting total urban water uses of a city, a region, or even a country, and especially used for residential water use forecasting. In spite of its popularity, the serious shortcomings of this method comes from the assumption that changes in urban water use is explained by the variable of population alone, with possible provision for changes over time in unit use as well. This is to say that the only independent variable X in Equation 2.1 is replaced by the number of population here. Therefore, the results are insensitive to most trends and changes known to affect urban water use, such as income, which are not under consideration in this method, and provides minimal information to those wishing to plan future facilities or management strategies (Baumann and Crews, 1985; Jones, et al., 1984).

In order to overcome the shortcomings of the per capita method, some developments of the method have been made. Other factors which might influence the change of water use, like income, water price, weather etc. have been considered qualitatively or quantitively in the forecast. An example with qualitative consideration of other factors beside population is provided by the forecast of Hansen et al. (1979), who forecast future municipal and industrial water use in Utah. However, if the other factors are considered quantitively, it falls into another category of forecasting methods--multiple coefficient methods which are discussed below.

Per Connection Coefficient

Per connection coefficient expresses future water use as a product of the expected future number of customer connections and a per connection water use coefficient. The difference from the per capita coefficient only results from using the number of connections (customers) in place of population as the explanatory variable. The value of the coefficient is usually extrapolated from past experience (Jones, et al., 1984).

The major advantage of the per connection method is reported to be that historical data on the number of connections to a water supply system are more readily available and more accurate than data on past population, which often must be roughly apportioned to the service area and interpolated between census years (Prasifka, 1988). This leads to better quality of estimates of past values of the per connection coefficient, and may result in improved extrapolation of this coefficient (Boland, 1985). The number of connections correlates better with the number of household units, which in turn correlates better with water use than total population does. Gottlieb (1963) and Boland (1978) have both presented empirical evidence for the better performance of the connections approach, compared to that which is based on resident population (Jones, et al., 1984).

In addition to offering increased accuracy, per connection methods enable projections to be disaggregated by type of use or customer class. This is particularly important if estimates of effectiveness of water use restrictions are liable to vary by customer class or type of use (Prasifka, 1988). Aside from these, the per connection method retains all of the advantages and disadvantages of the per capita method.

When the variance in size of the connections is too obvious, however, it is perhaps not a good choice to use this method. For example, one connection is a family, another connection is a building, and still another one is a neighbourhood which uses a common water supply station. It is not difficult to find cases like this in Chinese urban areas.

Unit Use Coefficient

Unit use coefficient, which could also be called other single coefficient methods, utilize a single explanatory variable, other than population or the number of customers connection, to forecast specific water use, such as the value of industrial product, number of employees, the area of land irrigated, the gross shopping area of floorspace, etc. As in the case of the per capita and the per connection coefficient methods, the use of a single variable may cause potentially important factors to be omitted. Unit use coefficient methods differ from the per capita and per connection methods, however, in that they are more often used in the context of sectorally disaggregated forecasts (Jones, et al., 1984).

These other explanatory variables that are commonly used include the value of industrial product, number of industrial employees, area irrigated, and so on. McCuen, Sutherland and Kim (1975), for example, chose gross shopping area floorspace to be the variable to forecast commercial water use. In China, industrial water use is often projected by multiplying industrial production value by unit value water use; and agricultural water use by multiplying the irrigated area by the unit area water use.

2.1.4 Multiple Coefficient Methods

Multiple coefficient methods express future water use as a mathematical function of two or more explanatory variables (Prasifka, 1988). A more general equation to show a multiple coefficient model would be of the following form:

$$Q = b_o + b_1X_1 + b_2X_2 + ... + b_nX_n + e \qquad (2.2)$$

in which Q is the quantity of water that is used or demanded over a given period of time; b_o is a constant; b_1 , b_2, ... and b_n are the coefficients; X_1, X_2 ... and X_n are the values of explanatory variables; and e is the error term (Metzer, 1989).

The dependent and independent variables in the above equation may represent the logistic or some other functions of the original items. The Cobb-Douglas Production Function model used by Xu Deqian (1992a; 1992b), for example, can be converted from its original form of

$$W(t) = b_0V(t)^{b1}W(t\text{-}1)^{b2} \qquad (2.3)$$

to the form of Equation 2.2 just by logging both sides of Equation 2.3.

The variables are chosen because of their past correlation with water use. The number of explanatory variables may range from two to several dozen, and the dependant variable may be aggregate or sectoral water use (Jones, et al., 1984).

Regression analysis is the statistical method usually used to estimate the coefficients.

Multiple coefficient methods require comparatively more data collection and higher levels of skill to develop the models. In practice, most difficulties are involved in the data collection, although any kind of data is available in theory.

Multiple coefficient methods, whether derived from a priori economic reasoning or not, are usually classified into two categories: those using econometric demand models and those employing requirement models (Baumann and Crews, 1985).

Requirement Models

Requirement models include variables having significant correlations with water use; these models do not necessarily include price of water or income of household or per capita income (Prasifka, 1988; Jones, et al., 1984; Baumann and Crews, 1985). Such models are used where water uses are not found to be influenced by the price of water or the correlation is unknown for various reasons. The data availability, for example, is likely to be one of the main reasons.

An application of the multiple requirement model is described by Burke (1970), who developed models of aggregate water use for 19 regions of the United States, using up to 17 explanatory variables. Kim and McCuen (1979) use this method to forecast commercial water use. Another example of the application of the multiple requirement model is that by Klimek (1972) who used the method for forecasting industrial water use.

Econometric Demand Models

Econometric demand models differ from requirement models only in that they are based on economic reasoning, which consider price and income as well as other variables.

Most demand models which appeared in the literature, or used to forecast water use, are sectoral in nature, and most pertain to the residential sector (Jones, et al., 1984). An early contribution was the residential water demand models reported in 1967 by Howe and Linaweaver. Numerous demand models have been developed since then. Young et al. (1985) use a demand model to project the water demand of the Denver Metropolitan area in the United States. The Seattle Water Department has used demand models for regional water planning, and also for medium and long term investment planning of facilities since 1973 (Dekay, 1985). Another application is described by Metzner (1989) in forecasting water demand for San Francisco. The application of demand models to industrial water use in South East and North West England can be found in the work of Rees (1969) and Smith (1986). Very few people have tried to introduce economic variables into Chinese urban water demand forecasting. An exception is the work of this author (Niu, 1986), in which per capita monthly income was considered. Another case is the work contributed by Xu Deqian (1992b), who combined the variables of per capita annual expenditure and per capita living space into his residential water demand forecasting model.

There were reports against the multiple regression methods. As pointed out by Power et al. (1981): "multiple regression models relating residential water consumption to each of the major factors affecting it were tried but the results were not accurate enough for the models to be used in a predictive mode." This was also the conclusion reached by Thackray, et al. (1978).

2.2 COMPUTERISED WATER DEMAND MANAGEMENT MODELS

Although any model can be incorporated into a computerized program and run by a computer, a popular and complicated one is the IWR-MAIN model. The model was originally developed by Hittman Associates Inc. in 1969, and modified by the U.S. Army Corps of Engineers Institute for Water Resources. The name IWR-MAIN comes from the abstraction of Institute for Water Resources-Municipal And Industrial Needs. The final product of the Corps' effort is the public-domain software package called "IWR-MAIN Water Use Forecasting System, Version 5.1." (Davis, et al., 1988).

One main characteristic of the model is that it disaggregates urban water use into a large number of categories. In general, four major sectors of water use are considered: (1) residential; (2) commercial/institutional; (3) industrial; and (4) public/unaccounted users. Each sector is further disaggregated as needed for forecasting purposes. As many as 284 individual water use categories can be used.

The forecasting methods used in the IWR-MAIN model are a mixture of the above methods, including the econometric demand model, unit use coefficient, and per capita coefficient, separately used for residential, industrial and commercial/institutional and some public water use sectors. In essence, as Dziegielewski and Boland (1989) point out, the IWR-MAIN model is only an advanced data management system. The selection of forecasting algorithms, coefficients, and assumptions must be made by the analyst himself based on knowledge of water uses in the study area and on understanding of the important factors that influence these uses both present and future (Dziegielewski and Boland, 1990).

The IWR-MAIN model is criticized by Wilson and Luke (1990). They argued that extreme and largely unconstrained disaggregation of water use will be a problem because the knowledge of water use is simply not good enough, i.e., thousands of individual calculations need to be predicted accurately by the model. They also suspect that the complexity of the model is an obscurity to model manipulation.

2.3 ALTERNATIVE FUTURES

Each assumption and explanatory variable projection contained in a water use forecast represents a condition likely to occur in the future. Sets of assumptions and projections are collectively termed alternative futures. To state it more clearly, the amount of water is dependent on the policies the Nation chooses to adopt, as well as upon socio-economic phenomena and changes in technology. These factors are interrelated to one another, and alternative combinations of them are possible. The alternative combinations of policies, life styles, socio-economic phenomena, and changes in technology are called alternative futures (NWC, 1976). Sometimes it is difficult to decide which of the alternative futures is the "most likely" to occur, especially when a range of policy options is to be investigated. McFarland and Hyatt (1973) have demonstrated the tremendous variation that may result from varying the underlying assumptions. In such a case, the likelihood of a number of alternative futures may be considered roughly equal, and a number of water use forecasts can be prepared, each corresponding to a unique set of assumptions and projections. By this means, the sensitivity of future water use computations to various combinations of assumptions can be determined, the level of uncertainty inherent in the forecast will be revealed, and a conclusion about probable future water demand can be drawn (Prasifka, 1988).

The first application of the alternative futures to water demand forecasting was proposed by Whitford (1970). The alternative futures are projected on the basis of various events that might occur in the future and might alter the water demand. Subjective estimates are made for the effect that each event would have on water use and of the probability of its occurrence. A baseline forecast is prepared, using one of the previous methods, in which the highest-probability outcome of all the postulated events is assumed. The baseline forecast is then modified to illustrate the effect of every possible influence of the uncertain factors (Whitford, 1972). The Whitford's model is also called Contingency Tree Method, because of the appearance of the diagram showing the sets of combinations (see Figure 9.2). This model was applied to industrial water use by Collins and Plummer (1974), and to water use for electric power generation by Young and Thompson (1973).

In addition to assembling the data used in the baseline forecast, the factors likely to affect future water use must be identified, and the likelihood of their effects need to be subjectively estimated. Boland and Mallory (1973) have suggested that these estimates give a misleading of the precision with which they appear to describe the variability of water demand forecasts. It may cause confusions for the people to use the results of forecasts. Other analysts, such as Collins and Plummer (1974), point out that the Contingency Tree method encourages planners to stop putting all their eggs in one basket by selecting one forecast. At least, as Prasifka (1988, p79-80) suggested, the alternative futures approach encourages planners to estimate the degree of flexibility appropriate for large-scale, long-term planning of a particular system.

2.4 CONSIDERING CONSERVATION

Water conservation is any beneficial reduction in water use or water losses (Prasifka, 1988, p100), which, in fact, is an alternative to increasing water supply. Water conservation can be achieved by an education campaign, adoption of water-saving facilities and technologies, and even by a major price increase. Jones et al. (1984) suggested that water conservation measures must be considered in forecasting water use under three sets of circumstances: (1) where water conservation measures have been implemented in the study area during the recent past, so that their effectiveness will not be reflected uniformly in historical water use data; (2) where definite commitments have been made to implement water conservation measures within the study area during the planning period; and/or (3) where water conservation is to be considered as an alternative to water supply augmentation in meeting projected needs.

Considering water conservation in water demand forecasting requires estimating the effectiveness of water conservation measures. The effectiveness of a water conservation measure can be expressed numerically as the quantity of water per unit time that is saved through the implementation of the measure, which is often obtained from the literature or from engineering analysis. In some cases, setting a numerical water conservation target to be achieved is also a way of considering water conservation in water demand forecasting (Sonnen and Evenson, 1979).

Water conservation measures affect various classes of water user and various types of water use quite unevenly. Aggregate estimates of conservation effectiveness are seldom reliable or transferable from one community to another (Jones, et al., 1984). Therefore, disaggregated water demand forecasting methods are necessary in conjunction with a considering of conservation measures. For the best results, individual forecasts should be prepared as part of a single, integrated forecasting process, so that consistent assumptions are employed throughout (Prasifka, 1988).

One application which considered water conservation in water demand forecasting has been worked out by Sonnen and Evenson (1979). Here the percentage conservation savings in each future period in indoor and outdoor uses of water in each of 40 possible land uses were anticipated. The conclusion drawn is that choosing a numerical conservation target to be achieved is more meaningful and yields more predictable results than price or price elasticity manipulations. Another study published recently is that by Nieswiadomy (1992), who treated conservation as a dummy variable. Although conservation is recognized and implemented in practice as an important strategy to alleviate the Chinese urban water shortage, very little research has been done in China on this topic.

2.5 SECTORAL DISAGGREGATION

Water use forecasts can be disaggregated in almost any way that water use can be broken down. The most common disaggregations are according to sectors (residential, industrial, commercial, etc.), time of year (summer, winter, etc.), and geographic subareas (Jones, et al., 1984).

The advantage of disaggregation is that it allows each individual sector to be analyzed and forecast in terms of explanatory variables which relate specifically to that factor. In addition, disaggregation provides detailed forecasts which may be needed for planning purposes, or to evaluate specific strategies such as water conservation.

In practice, sectoral disaggregation in water demand forecasts can range from two to hundreds of sectors. In the IWR-MAIN model, for example, as many as 284 individual sectors can be classified (Davis, et al., 1988). The Chinese urban water uses are often divided into two categories: water used for production, and that used for other purposes. In general, water use sectors are recognized as residential, industrial, agricultural, commercial and public; but there is no uniform classification in water demand forecasting. Disaggregation is mainly decided by data availability.

According to the experience of Seattle Water Department, disaggregation results in the most accurate water demand forecasts (Dekay, 1985). The problem is that the more detailed disaggregation, the more data is needed, not only of past records, but of estimates or assumptions about the future as well. As Wilson and Luke (1990) point out, knowledge of water use is not good enough to reveal all the determinants and the relationships between them and water use. Only where sufficient data of an adequate quality is available, can a disaggregate model produce more accurate and useful forecasts than the simpler, aggregate models.

2.6 LIMITATIONS

Water demand forecasting, especially long-term forecasting, has been greatly criticized in terms of its basis, methods, assumptions, and the data used in the analysis (Twort, 1976; Domokos, Weber and Duckstein, 1976). The most serious critique comes from the comparison between the forecasts made decades ago and the reality which occurred. After comparing a couple of forecasts and the actual outcomes which occurred 20 years later, a conclusion drawn by Osborn et al. (1986) is that water use forecasts, regardless of the time-frame or the forecast method employed, are likely to always be highly inaccurate. This kind of critique is not only directed towards water demand forecasts, but is applicable to any long-term forecast, such as energy demand forecast (Ascher, 1978). The weakness of long-term forecasts, whether for water demand, energy demand, or any other resources demand, results from common roots as put below.

2.6.1 Assumptions

All forecasts rest on assumptions to some varied degree, either explicitly or implicitly. In the extrapolation method, for example, it is assumed that the trend of the past will continue into the future; and in the single or multiple regression methods it is assumed that the regression relationship between the dependent and independent variables identified from past experience will remain constant in the future time. On the other hand, if assumptions are not based on the past experience, they will be based on the forecaster's subjective judgements about what is the "most likely" future, as in those judgemental methods discussed in previous sections. Obviously, there will be no forecast if there are no assumptions.

No one can say that assumptions are totally rootless or without foundation; but they may be subject to bias and error. This kind of weakness in forecasting is not completely avoidable, and hence, neither are the critiques.

From this point of view, all forecasts are conditional ones, and there is no absolute forecast. A failure of a forecast may be caused by any false assumption, or by a wrong condition, or because of the uncertainty in the future about the size of explanatory variables.

A complicated forecast model is often composed of many assumptions. The assumptions can be generally divided into two major categories: (1) those based on past experience, and (2) those based on subjective judgement. The relationship between the water uses and factors affecting water use revealed by analyses based on past experience can be put into the first category. These relationships should not be recognized as assumptions if they are proven to be true. Unfortunately, most of the relationships have not been finally established nor proven yet. However, the first category of assumptions ought be treated separately from the second ones. A forecast should be assessed not only in terms of whether or not the results are accurate, but also whether all the assumptions and the whole process upon which the forecast is made are true or false. The only way to prevent too many critiques may be to make the assumptions more explicit.

2.6.2 Relying on Other's Forecasts

As mentioned before, water demand is affected by many factors, including demographic, socio-economic, technological, and physical ones. When causal forecasting methods are employed, it is impossible for the water demand forecaster to project all the unknown values of the related factors by herself or himself. It would be necessary to adopt forecasts made for of factors by other professionals in related disciplines. In such a case, inaccuracy of a water demand forecast may be caused by adoption of an inaccurate forecast for a relevant variable. The Kielder water scheme in the North East England, for instance, failed to materialize its expected growth in water consumption owing to the changing fortunes of industry particularly on Teeside (Brady, 1985).

If water demand forecasters attempt to forecast all the related factors, the result of the water demand forecast would be more subject to criticism than the case of merely relying on other people's forecasts. This is because nobody can manage to undertake such a multi-disciplinary job. There is no way for water demand forecasters to escape from this kind of pitfall unless forecasting in the various disciplines can be improved or made to be more "reliable".

2.6.3 Data Availability and Reliability

All forecasts of water demand are based on records of past uses. As mentioned in previous sections, the difficulties are that data which is required is not always available, and often published figures for past water uses are unreliable. This has arisen because there is no uniformity in the classification of water uses; estimation of the amount of water used is still the major way to obtain water use data rather than that recorded by water-meters. Even when water-meters are installed, water use data can be recorded irregularly, and can be improperly aggregated. The scarcity of reliable figures for water demand analysis and forecasting in Britain during 1970's was reported by Twort (1976). The situation has been improving since then, but not as quickly as expected. The unavailability and unreliability of data are still major obstacles in water demand forecasting, especially in water-rich countries and areas, because the richer the water resources, the less effort is devoted to measure various water uses and to take detail records. In Britain, for example, installing water-meters in households is still under debate, while this has become compulsory in Chinese urban areas. This is mainly due to the serious water shortage that has occurred in China, but has not yet, or is much less serious if it has, occurred in Britain, because water resources in Britain is comparatively much richer than that in China.

Based on unreliable past records, any forecast may present a totally untrue picture. Theoretically, this kind of pitfall in water demand forecasting, unlike that caused by assumptions, is not unavoidable. With improvement in management and methods used in data collection, it can be overcome.

From another point of view, it may be argued that social statistical records, including the records of water uses, are not one hundred percent accurate. A certain extent of error, perhaps, should be treated as normal or acceptable. However, as Encel et al. (1975) suggested, for presenting conclusions, forecasters should point out the background and the margins of errors of the data employed, and attempt to assess their implications through, for instance, sensitivity analysis and testing.

2.7 SUMMARY

In this chapter, the methods used in forecasting water demand, including judgemental methods, extrapolative methods, single coefficient methods, and multiple coefficient methods in the literature were reviewed. Actually, this is only a convenient classification. In practice, the methods that have been widely used are varied mixtures of the above ones. Limitations exist in the forecasting of water demand, which come from some common roots, i.e relying on assumptions, other's projections, and unavailable or unreliable data, etc. Besides these, there are various disadvantages in the methods used in water demand forecasting, and the knowledge about the relationships between water use and the factors influencing it is still limited. Although valuable attempts have been made, such as making disaggregation, considering conservation, taking alternative futures into account, building up computerized forecasting models, and so on, consistent conclusions have not been achieved. Many arguments, debates, and critiques are involved in the area of water demand forecasting.

Most of the researches reviewed in the literature were carried out based on or with respect to various situations in America. Studies on forecasting water demand in China may be said to be still in its infancy. Although water demand forecasts have been made from city-wide scale to nation-wide scale, much less effort has been spent on how to forecast water demand. Therefore, in addition to learning from the others, it is necessary to have a systematic approach to water demand forecasting in the Chinese context.

PART I

CHINESE URBAN WATER USE SYSTEM ANALYSIS

INTRODUCTION

This part consists of six chapters i.e. Chapter Three to Chapter Eight. Its objective is to understand the Chinese urban water use system, including attempts to find significant variables which affect urban water uses from a long-term perspective, and to explain patterns of urban water use in China. Understanding and forecasting are inherently related. The further purpose of understanding, or explaining, may be regarded as projecting, or forecasting (Manicas, 1987, p289). This part is essentially to provide a basis for the next part: urban water use forecasting.

Although there is no standard classification, urban water use in this research is generally divided into four categories according to the availability of data. They are residential, industrial, agricultural, and commercial water uses, which are separately analysed in Chapter Four to Chapter Seven. Chapter Three gives some background to the Chinese urban water supply system, including historical and current status. Chapter Eight investigates the influences of some major government policies on Chinese urban water uses.

In many urban water studies, agricultural water use is not taken into account. Whether or not to include agricultural water use in an urban water use forecast is greatly dependent on the situation of the urban area, and the purpose of the forecast. Where there are no farming activities, or their scale is too small or negligible, it is, of course, unnecessary to consider the agricultural sector in an urban water use forecast. However, this kind of situation is extremely rare in Chinese cities.

Agricultural water use is often supplied independent of the public water supply system. It has its own water sources and supply facilities. When the aim of a forecast is for the management or investment appraisal of a public water supply company, then it is possible to exclude agricultural water use in the analysis.

However, if the forecast of water use is for the whole urban area, for example in the case of regional water resources planning, agricultural water use should be included. In general terms, agricultural water use is part of urban water use, and it ought to be taken into account when urban water use is considered as a regional issue.

In the analysis, both quantitative and qualitative methods are used. The single regression method is widely used to judge or assess the significance of variables. Due to the unavailability of some data, it is not possible to assess all the variables by using regression analysis. Sometimes qualitative or comparative analysis is used instead, or is combined with the regression method.

Two major characteristics of the analyses are worthy of mention here:

Firstly, in each category of urban water use, a variable that is considered to be the most important or basic factor to affect the category of urban water use is picked out and treated as the variable affecting the demand for water. Other factors are regarded to affect the intensity of water use, i.e. per unit water use (per capita, per unit value, per unit area, etc.). Thus, in the analysis, only the factor affecting the demand for water is considered to have a relation to the total water use or demand, other factors are only considered to have a relation to the per unit water use.

The distinction between affecting water demand and affecting the intensity of water use has been used, but without being identified by many researchers. For example, per capita water use is often used in lieu of total water use in analysing relationships for residential water use (Darr, Feldman and Kamen, 1976). An assumption behind this is that future water use is determined by the total population multiplied by the projected per capita water use.

Using this distinction makes the analysis more explicit, and avoids some interference among the factors. For instance, family size, or the number of people in a household, is thought to be a factor influencing residential water use. The assumption is that household water use rises more slowly than the number of residents, other things being equal, i.e. there are economies of scale. It is clear that if the assumption is true, the relationship between household water use and the number of people resident in the house is not linear. When both population and family size need to be considered in forecasting a city's residential water use, the question appears to be a little more complicated. However, by adopting this distinction, it becomes clearer and easier to understand. Family size can be put into the category of variables affecting the intensity of water use while population is the factor affecting the demand for water. The relationship between per capita water use and family size can be analysed by using linear regression or any other appropriate function. Without this distinction, if per capita water use is regressed with family size, confusions can arise. The distinction has some relationships with the single coefficient forecasting methods, or it may be seen as a development from the per capita, per unit, or other single coefficient forecasting methods.

Secondly, data representing different levels of aggregation are used in analysing the relationship between a variable and water use, or intensity of water use, in order to see how the relationship changes with the change of scale that the data cover, for example, from a national scale to a city scale, or even to a household scale. Some interesting results have been found.

The urban water use system is a very complicated system. It has relationships with almost every aspect of urban life. As a starting point, the following flowchart (Figure I.1) gives a general impression of the complexity, the structure of this Part, and some general information about each sector's classification and the way that the analysis will proceed.

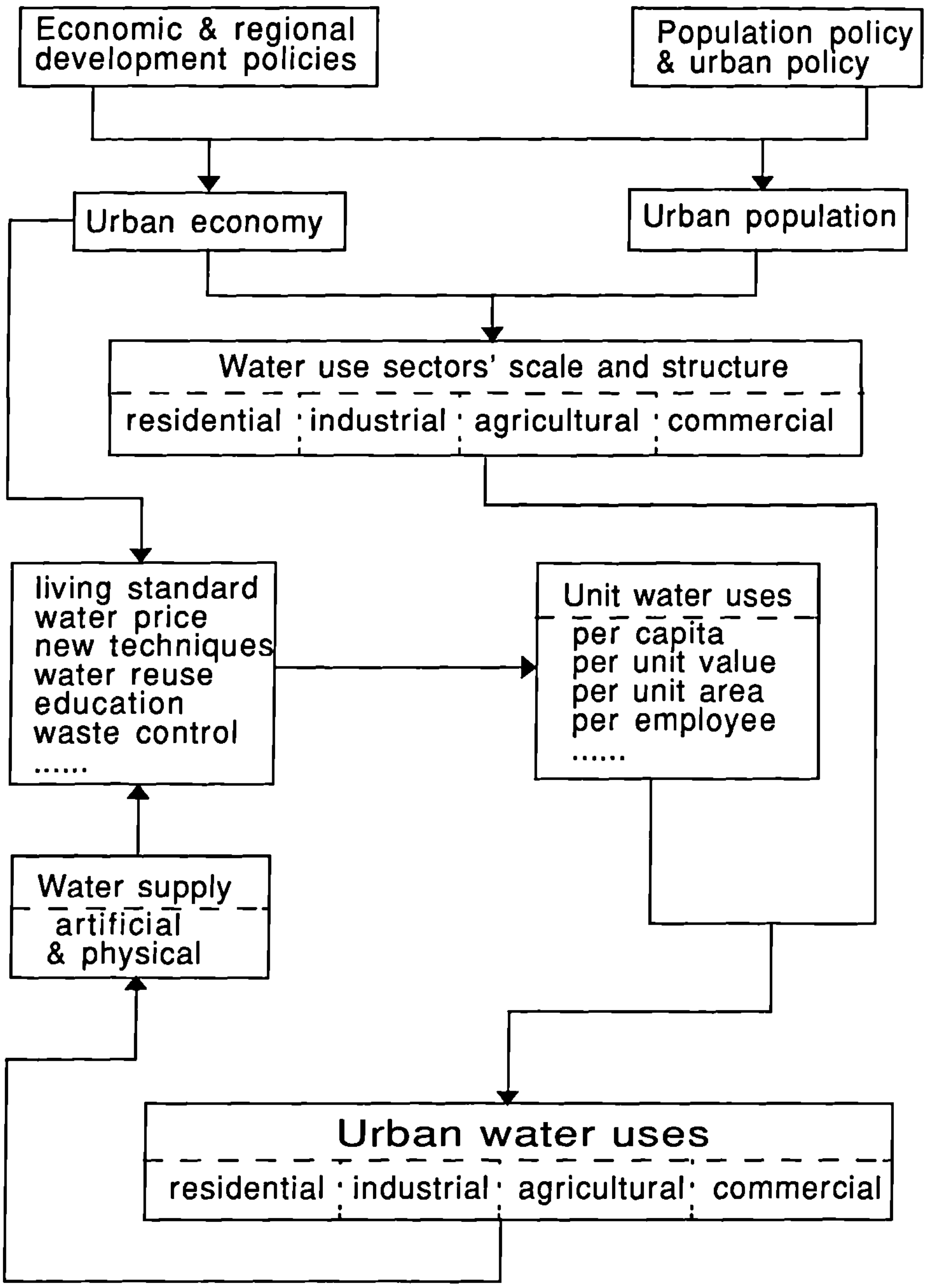


Figure I.1 Urban Water Use System

Chapter Three
CHINESE URBAN WATER SUPPLY: THE GENERAL EXISTING SITUATION

3.1 BRIEF HISTORY, OWNERSHIP AND MANAGEMENT

The first modern urban water supply treatment works in China started in Shanghai in 1893. After that date, water supply facilities were successively constructed in Qingdao, Tianjin, Guangzhou, Wuhan, Beijing, Jiaozuo, Nanjing, Taiyuan, and so on. However, up to 1949, only 58 cities and 14 towns in China had water supply facilities, and most of them had very limited capacity that could only meet a small part of the total urban water demand (Zhu Tiezhen, 1987). During 1930s and 1940s, for example, only about 1% of households used tap water in Beijing (Li Kun, 1991). Since the establishment of the People's Republic of China, and especially since the economic reform that started in late 1970s, the urban water supply capacity has been increased greatly. At present, as many as 467 cities and more than 2,000 towns have public water supply facilities; and more than 80 percent of the urban population have been served by the public water supply system.

The water supply company in each city is responsible for supplying water to the various urban water users. They are state-owned organizations and directly administered by the Municipal Construction Bureau. A national investigation in 1985 revealed that water companies throughout the country supplied between 11% to 90% of the total urban water uses. This varied among cities (Table 3-1). The additional supply came mainly from factories or enterprises that had their own water supply facilities. According to the Chinese Water Law published in 1988 (The National People's Congress, 1988), water resources are state-owned and their development is generally under the control of the water authority in the State Council. The urban water supply, whether from the water company or individual factories, is directly or indirectly managed by the urban water supply authority, which is a branch of the Municipal Construction Bureau.

Table 3-1 Chinese Urban Water Supply

Cities	Public Water Supply Capacity (10^4 m^3/day)	%	Individual Water Supply Capacity (10^4 m^3/day)	%
Beijing	164.0	58.7	115.6	41.3
Tianjin	114.7	76.6	35.1	23.4
Shijiazhuang	34.1	20.6	131.5	79.4
Taiyuan	34.0	53.1	30.0	46.9
Huhhot	17.2	60.1	11.4	39.9
Shenyang	110.0	75.3	36.0	24.7
Changchun	33.0	84.6	6.0	15.4
Harbin	37.0	64.9	20.0	35.1
Shanghai	377.7	62.0	250.0	38.0
Nanjing	66.0	11.4	510.0	88.6
Hangzhou	48.3	73.3	17.6	26.7
Hefei	25.0	48.4	27.6	51.6
Fuzhou	33.5	59.9	22.4	40.1
Nanchang	42.3	34.2	21.5	65.8
Jinan	48.5	65.1	6.0	34.9
Zhengzhou	50.0	80.6	12.0	19.4
Changsha	44.0	68.8	20.0	31.2
Guangzhou	201.6	46.3	234.1	53.7
Nanning	41.0	71.9	16.0	28.1
Chengdu	39.1	80.8	9.3	19.2
Chongqing	48.0	13.2	315.0	86.8
Guiyang	29.0	55.8	23.0	44.2
Lhasa	1.0	33.3	2.0	66.7
Xian	54.0	63.5	31.0	36.5
Lanzhou	118.0	90.4	12.5	9.6
Xining	14.5	54.9	11.9	45.1
Yinchuan	4.5	30.0	10.5	70.0
Urumuqi	8.7	51.5	8.2	48.5

Source: The State Statistical Bureau of China, 1986a.

The investment to build or enlarge the public water supply facilities used to come directly from central and local governments. The plan and decision to construct waterworks were made by the municipal planning organizations. The water companies had limited rights and limited financial capability to develop their own capacity. However, since the economic reform, and especially since 1985, the situation has been changing. There are now usually three sources from which urban water companies could obtain money to develop or improve their services:

(1) loans from the national banks;

(2) charges for the increase of urban service capacity from the new-build units collected by local governments by way of a once-for-all capital payment which is translated to the water company. For example, when a new plant is planned to be built in an urban area, except for other charges that it has to pay, such as land use conversion fees, it also has to pay the local government an amount of money for its use of public service facilities such as water, electricity, transportation, etc. Money collected by the government is annually distributed to the public service companies. The policy has been implemented in China since 1980s in order to improve the public service that is considered as a major obstacle in developing the Chinese economy; and

(3) retention of part of the profits made by water companies, which previously was all handed back to national government finances. Some urban water companies have been given rights to retain all of their profits to build or repair their water supply facilities. Guangzhou water company, for example, has been given the right to use all of the profit that was previously passed on to the Municipal Finance, to develop its capacity (The State Statistical Bureau of China, 1988c). Meanwhile, central and local governments have stopped providing any financial support. At present, there is a trend in China for water companies to manage and develop themselves in the market economy under the macro-guidance of central and local governments.

The price of water is generally controlled by the central government, because the State Council is in charge of policy-making about setting the prices of commercial goods. However, among the cities, there are some differences in the water price structures. This arises because water price is directly decided by the provincial Price-control Bureau, based on the general policy made by the central government, with consideration of the local situation. In previous decades, water prices remained low and did not change much because water supply was only to serve productions and was seen as a public benefit to improve the quality of people's lives rather than to make profits. For example, in Xining Water Supply Company, the price of residential water use has remained unchanged, at 0.18 yuan per cubic metre, since 1962. A national survey in 1987 revealed that expenditure on water by each family only accounted for about 0.22%-0.32% of the total household's annual consumption expenditure (The State Statistical Bureau of China, 1987a).

Today, the ideology about services in China is changing. An implemental rule issued by the Ministry of Construction and the State Planning Committee for setting the price of water, directed water companies to make a little profit from residential water use and reasonable profits from industrial and commercial water uses (The Ministry of Urban and Country Construction and Environment Conservation and the State Planning Committee, 1990). Water supply companies can set water prices of various water uses according to this rule, after obtaining the approval of the Provincial Price-control Bureau. Table 3-2 presents an example of the prices of various water uses that are operated by Lanzhou water company. It is clear from this table that residential water supply is the cheapest, next industrial water, and lastly commercial water. Water prices have been raised in recent years in many Chinese cities because of inflation and in order to encourage more economical uses of water. In the same document issued by the Chinese Construction Ministry and the State Planning Committee (1990), it was also suggested that water prices should be changed annually.

Table 3-2 Water Prices for Different Uses in Lanzhou

Water Uese	Water Prices (in Yuan/cubic metre)	
	Current	Before 1988
Less Treated Industrial Water	0.10	0.07
Treated Industrial Water	0.25	0.20
Filtered Industrial Water	0.40	0.24
Commercial Water	0.50	0.24
Residential Water	0.25	0.12

Source: Lanzhou Water Supply Company.

In order to encourage people to economize on water effectively, especially in industrial uses, many Chinese cities have adopted increasing rate structures. This is based on the water use quota, or standard quantity, set for various industrial products by national or local authorities. One of these documents for trial implementation was issued jointly by the Construction Ministry and the State Economic Committee in 1984. If water used for producing a product in a plant is more than the quota, the price of water for the overdrawn part will be doubled or even increased to ten times, according to the quantity of water overused and local regulations. In Beijing, for example, the overuse of water for industrial purposes can be charged from two to fifty times that of the basic water price; and in Xining, from two to five times of the basic price.

An organization called the Water Economization Office (WEO) has been established in Chinese cities during the last few years. This is responsible for the encouragement of conservation and the prosecution of users that waste water. They are independent of the water supply companies, and under the control of local governments. The increasing block rate price structure adopted in cities is mainly made by the WEO, enforced by the government, and accepted by water supply companies. Water companies, which have become profit-making enterprises, may be careless about water waste behaviour; and they may not care about who has not got enough water in circumstances when supply capacity cannot meet the demand, and when there is no competition. This is the situation of water supply in many Chinese cities, and that is why the WEO is necessary to be established independently from water companies. The link between WEO and the water companies is the government that controls them. The manager of Xining Water Supply Company expressed that they do not like the rule of varied prices for different water uses and the increasing block rate price structure, because they increase management difficulties.

3.2 URBANIZATION AND INCREASED URBAN WATER USE

From 1949 to 1991, the number of administrative cities in China increased from 67 to 479. Metropolises with over 1 million people increased from 6 to 31. During the period, the urban population increased from 57.6 million to 150 million. The fastest change occurred during the last ten years. Table 3-3 details the change in the number of Chinese cities since 1949 by population size.

With the development of urbanization, especially industrialization in the urban areas, urban water use has increased dramatically (Figure 3.1). The total urban water supplied by the urban water facilities, including public water companies and individual factories or enterprises, increased from 0.95 billion cubic metres in 1957 to 39.3 billion cubic metres in 1989. Of this, residential water use increased 16 times, from 0.55 billion cubic metres to 9.13 billion cubic metres; industrial and other water uses increased by as much as 74 times (see Table 3-4). The latent urban water demand is even greater than the real water supplied because of the existing urban water shortage. According to the analysis of Lei Niansheng (1987), the total quantity of urban water supply increased at a rate of 17.20% per year from 1952 to 1962, 8.20% from 1963 to 1972, and 7.26% from

1973 to 1985. The high rate of increase during 1950s and early 1960s was attributed to the low initial base level.

Table 3-3 Change in Number of Chinese Cities

	POPULATION SIZE				
YEAR	>1m	o.5-1m	0.2-0.5m	<0.2m	Total
1949	6	10	19	34	69
1957	10	18	36	114	178
1960	15	24	32	128	199
1961	15	22	33	138	208
1963	15	18	54	87	174
1965	13	18	43	97	171
1970	11	21	47	97	176
1975	13	25	52	95	185
1978	13	27	60	92	192
1979	16	27	67	106	216
1980	15	30	70	108	223
1981	18	28	70	117	233
1982	19	29	70	127	245
1983	19	29	73	168	289
1984	19	31	81	169	300
1985	21	31	94	178	324
1986	23	31	95	204	353
1987	25	30	103	224	382
1988	28	30	110	266	434
1989	31	28	117	291	450
1990	31	28	119	289	467
1991	31	30	121	297	479

Note: ">1m" means the population of a city is over 1 million; "0.5-1m" means the population is between 500 thousand and 1 million; and so on.

Source: Zhu, T., 1987; The State Statistical Bureau of China, 1990a, 1988b, 1989b, 1990b, 1991b; Chen X., 1991.

Table 3-4 Change in Chinese Urban Water Supply Capacity

Year	Total (in 10^6 m^3)	Residential Use (in 10^6 m^3)	Per Capita Use (in m^3/Year)
1957	0.95	0.55	9.2
1975	6.16	2.27	30.7
1980	8.83	3.39	38.0
1982	10.11	3.91	48.3
1984	11.76	4.66	52.3
1985	12.80	5.19	55.1
1986	27.74	6.91	58.8
1987	29.85	7.60	59.9
1988	33.86	8.74	62.2
1989	39.37	9.31	62.9

Source: The State Statistical Bureau of China, 1985a-89a.

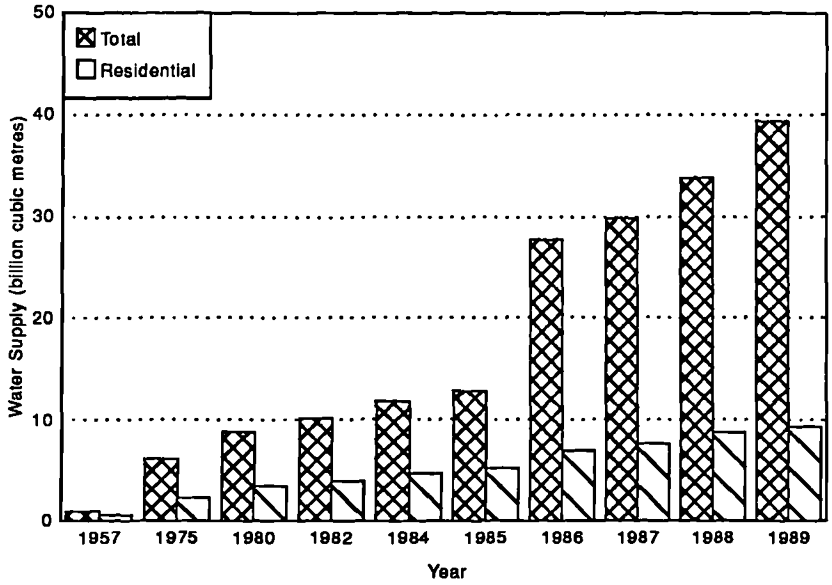


Figure 3.1 Increase of urban water supply in China

3.3 WATER SHORTAGE AND ECONOMIZATION MOVEMENT

At present, nearly three hundred cities in the country face water shortage problem. The total urban water supply is, on average, about 10 million cubic metres per day less than what is demanded. Many cities have to restrict water use by time and/or by quantity; factories and enterprises have no choice but to shut or curtail production during the peak time of water use. The urban water crisis has become a major obstacle to the development of the Chinese urban economy and the improvement of living standards (The Ministry of Urban and Country Construction and Environment Conservation, and the State Planning Committee, 1990). A survey in 94 cities in Shandong, Liaoning, Jiangsu, Heilongjiang and Shannxi provinces revealed that in 1989 about 12.7 billion yuan (around 1.48 billion pounds) was lost in industrial output in these cities because of shortage of or insufficient water supply (People's Daily, 20th July

1990). Some people have been arguing that the "water crisis" is more important than the country's widely acknowledged energy problems (Lampton, 1987).

The basic reason for the serious urban water crisis is the fact that the development of water resources and the construction of waterworks has not matched the speed of urbanization and industrialization, that is to say urban water demand increases faster than the speed of the increase in capacity of urban water supply. It may be argued that the shortage of water is, in fact, a shortage of vision or forethought. If more research on forecasting had been done and more investment had been made, there would not be such a serious urban water problem today.

While lack of forecasting and investment have contributed to the urban water shortage, other factors can also be found in various cities. The northern and coastal cities, except those located along or near big rivers, rely on ground water or surface water collected in the local area. Under some situations, urban water demand exceeds the natural water supply, thus creating a water crisis. In Beijing, for example, annual local exploitable water resources amount to 4.72 billion cubic metres with a 50% confidence variation because of the variance in precipitation from year to year. But in 1978 the total water used had already reached to 4.60 billion cubic metres (Li Bofa, 1984). Overdrawing of ground water causes drops in the water table year by year, and this creates an increasing more serious urban water crisis. Without channelling water from other regions, this kind of urban water problem cannot be thoroughly resolved except by introducing decentralisation policies to reduce the urban water use. One policy option would be for the government to decentralise industry and population. If the price of water for a factory becomes extremely high it may be more efficient for that factory to operate elsewhere in any case.

Another major kind of water shortage is caused by insufficient water supply facilities, or insufficient investment. The water source itself, may not be a problem, compared to finance. By installing more water supply facilities, water shortage should be overcome. This situation is typical in some of the southern cities and in most of small and mid-size cities, especially in the fast developing regions which have appeared in the last ten years. In Shenzhen, which has been developed as a modern city from a small town of ten years ago, for example, the water supply capacity is currently 450 thousand cubic metres per day, but the demand is over 600 thousand cubic metres (People's Daily, 29th Nov. 1991)

In order to overcome the constraints from urban water shortages, the government has been trying very hard to encourage people to save water in various uses. In 1984, the State Council firstly promulgated a circular to ask people to economize on water uses. Since 1989, the regulation for the management of economizing on urban water use has been in operation. In 1990, the State Council again approved and distributed the report on further economizing of urban water uses, jointly drawn by the Construction Ministry and the State Planning Committee.

In this regulation, except for some general items such as the purposes of saving water, detailed methods to force water saving are declared and made compulsory. For example:

(1) in Item 7 of the regulation, the reuse rate of industrial water must be higher than 40% (excluding thermoelectric plants); otherwise, the increase of industrial water supply in the city is not permitted.

(2) in Item 8, the drawing of water from the ground to meet self needs requires permission from the administrative authorities.

(3) in Item 12, residential water is charged according to the quantity of water used by each family. Every household should has its own water-meter; and

(4) in Item 19, households without water-meters are required to install one within a certain time period, failing which, they will be fined or punished by having their water supply limited.

These regulations are applied to the whole country. Local authorities are asked to make more exact water saving and conservation regulations based on their own specific situations in relation to water resources and water supply. Up to the end of 1991, most cities had issued their local water economization regulations (People's Daily, 1st July 1992). The conservation of water has become a political target in both urban and rural areas in China, especially in areas that have very serious water shortage problems. When this author travelled in China in October and November 1992, many slogans and posters about water economization were seen inside buses and hanging over bus stops in Beijing, and on the outside walls of farmers' houses in the countryside of the North China Plain.

The water economization movement has made some achievements, and a further campaign is planned. It was reported that as much as 6.3 billion cubic metres of water has been saved from 1984 to 1990; on average, about 0.9 billion cubic metres was saved per year. This is equivalent to a saving of 2.3 billion yuan investment that would have been necessary to increase water supply by the same amount. The unit use of water in industries dropped dramatically. It declined from 459 cubic metres per 10 thousand yuan of productive value in 1984 to 270 cubic metres in 1990, which is less than 60% of the former (The Ministry of Urban and Country Construction and Environment Conservation, and the State Planning Committee, 1990).

To find new sources for the increase of the urban water supply capacity, and to economize on water uses, are recognized as the only two ways to deal with the Chinese urban water crisis. For many of the large and coastal cities, it is not easy to find new water sources to increase water supply, or it is too costly, so that economizing on water will continue to be the major strategy to overcome the urban water crisis in the foreseeable future. Of course, the strategy is flexible from city to city, depending on the local situations.

Chapter Four
RESIDENTIAL WATER USE

4.1 INTRODUCTION

On average, about one quarter of the water supplied by Chinese urban water companies today is consumed for living purposes. This portion of water consumption in China is called residential water use. It is composed of two major parts: the domestic water use that serves purposes such as cooking, washing, bathing, toilet flushing, and so on; and public water use that serves public purposes such as schools, hospitals, institutions, fire fighting, public lawns and amenity belts, etc.

The outdoor water use for car washing and lawn sprinkling, which takes a considerable magnitude in some western countries, is negligible in the Chinese case, because it is currently rare to have private cars or lawns attached to residences in Chinese urban areas.

The public, or sometimes called institutional, water use, is usually treated separately from residential water use by researchers in America and some other countries. But it is impossible to do the same in the study of Chinese residential water use because of the shortage of data. In the available statistical books or materials, including national, local, and individual water companies' statistics, water used for public purposes are wholly included within the domestic water use, and there is no further subdivision.

The data on residential water use adopted in the following analyses are not unified in terms of their contents. Besides the basic part: the domestic water use, some data include public water use, like the inter-city residential water use data; other data exclude it, like the neighbourhood household data; and furthermore, commercial water use data are sometimes included, like some of the city case data. This is more or less a problem for the analysis of the association between residential water use and other factors that affect it. However, the differences in the data are ignored during the analysis for two simple reasons: (1) the public and/or commercial water uses usually takes a very small part of urban water uses (about 5%) compared with the residential water use (about 25%); (2) public and commercial water uses are assumed to be related to the residential water use.

4.2 FACTORS AFFECTING RESIDENTIAL WATER USE

It is generally agreed that the level of residential water use is a response to its environment, including physical, social and economic conditions. Environmental conditions may be reduced to a number of factors. The effect of a specific factor may be isolated if other factors are assumed to be constant. This approach offers several advantages as Grima (1972, p33) points out:

> "(1) It is suited to quantitative analysis so that under certain conditions conclusions which are correct within specific confidence limits may be stated.
>
> (2) It explores some of the interrelationships between residential water use and selected environmental factors.
>
> (3) Statements of wide applicability may be made about the effects of variables that are not unique in time and space.
>
> (4) The tentative conclusions not only explore the pattern of man's behaviour in using a basic natural resource but also have implications for improving the quality of life by better planning."

These advantages are essential and beneficial to forecasting water demand. To find the significant or principal predictors, especially their relations to water use, is one of the major preoccupations of forecasters. The relationships between urban water uses and the environmental factors using historical data is almost always the first step in the analysis.

It is not difficult to imagine that many factors have some relationships with residential water use. This author estimates that factors that potentially affect the Chinese urban residential water use are numerous, as listed in Table 4-1. They are generally divided into four categories: physical, economic, social, and individual factors. There are more indicators, which can be used as explanatory variables of residential water use, than the number of factors listed, because several indicators may be used to represent one factor. The Level of income, for example, may be represented by per capita annual income, by household annual income, or by housing value.

The difficulty is finding out which are the significant factors, or explanatory variables; and how the change in one factor causes a corresponding change in water use. In particular, the most difficult problem is estimating how the simultaneous changes of several significant variables will be reflected in water use. Efforts have been made by using simple and multiple regression methods to find out which significant variables play a dominant role in affecting residential water use (Grima, 1972; Darr, Feldman & Kamen, 1976).

Inconsistent results have been revealed by varied researchers in the literature. Some variables found to be significant in affecting residential water use in some studies, are found to be insignificant in others. Price of water, for example, is the factor which has attracted the attention of most researchers. Carver and Boland (1980) reports that seasonal price elasticities of water use for Washington, D.C. are "not significantly different from zero"; and Berry and Bonem (1974) also reports that they did not find price to be a significant determinant of average daily municipal use. These results contrast with those of Howe and Linaweaver (1967) in which a seasonal price elasticity of -1.6 is reported. Another question about water price that is still under debate is whether consumers react to marginal or average prices (Nieswiadomy, 1992).

Table 4-1 Factors Affecting Residential Water Use

A. Physical Factors

1. Temperature (change seasonally, annually, and spatially)
2. Precipitation (change seasonally, annually, and spatially)
3. Natural water availability and dependability

B. Economic Factors

a. In the aspect of demand

1. Level of income
2. Housing condition (type, size, facilities, etc.)

b. In the aspect of supply or management

1. Price of water
2. Metering
3. Ways of water supply (tap, neighbourhood station, etc.)
4. Pressure of distribution
5. Ways of charge
6. Regulation/prohibition on water uses (sufficient or not)
7. Waste control

C. Social Factors

1. Population served
2. Level of urbanization
3. Regional or religious customs in using water
4. Ideology of water conservation
5. Education or propaganda for encouraging to save water
6. Occurrence of holidays

D. Household Factors (Individual Factors)

1. Personal habits in using water
2. Family size
3. The number of days that the family is not in residence

There are similar debates about other factors, like conservation, technologies relating to residential water use, e.g. better design of household durable goods using water (Nieswiadomy, 1992). Furthermore, an argument raised by Murdock, et al. (1991) suggests that demographic and socio-economic variables, such as the age of the householder, racial or ethical status, and household composition markedly affect water use, and are often of relatively greater importance than economic, climatic or other physical factors in explaining per capita water use. Therefore, although it is essential to understand the key determinants of water usage (Hishleifer, et al., 1960), a consensus on the proper determinants has not been established.

According to Miaou (1986), the independent variables commonly employed to describe the long-term water use variation in America are: population, average income level, water price, housing density, and number of water connections. In China, some variables like population, per capita income, housing condition, water availability, and personal customs, are commonly agreed to affect residential water use (Yang, Ren, et al., 1984), but very little effort has been made to find how important the role of each factor is.

The following analyses, which are limited by the availability of data, try to establish or find out whether some variables, including population, per capita income, annual average temperature, annual precipitation, and family size, play significant roles in influencing Chinese urban residential water use, in which population is recognized as the variable affecting the demand for water, while the others are treated as variables which affect the intensity of water use. Different scales of aggregated data are used in order to test how the functions of the variables change with different scale levels. However, because of limited data availability, the impacts of some other variables, like water shortage restriction, conservation movement, level of urbanization, price of water, etc. are assessed generally in qualitative terms.

4.3. POPULATION AND RESIDENTIAL WATER DEMAND

Population is considered to be an important factor affecting residential water use for the very reason that it is people themselves who use water! In the popular water demand forecasting method, the per capita method, population is the only predictor adopted to forecast water requirements. When the per capita method is used, the question raised is that of how much of the change in residential water use is caused by the change in population, in other words, how important is the role of population in influencing the residential water use. In order to obtain an answer to this question, the relationship between population and residential water use is examined under three scales: an inter-city scale, a city scale, and a household scale.

4.3.1 An Inter-city Analysis

In the analysis, a combined cross-section and time-series database is used. From the Chinese Statistical Year-book, thirty-one cities' yearly residential water use data, including public and commercial water uses, and data of the populations served from 1985 to 1991 were obtained. The correlation between water use and population is analysed by using a simple linear regression method. The result is shown in Figure 4.1, and the equation obtained is:

$$Q_r = \underset{(963.5627)}{-2536.3125} + \underset{(3.94492)}{86.2223}P_p \tag{4.1}$$

Q_r is the quantity of residential water used in ten-thousand cubic metres; P_p is the number of population served in ten-thousand persons; and the figures in brackets are the standard errors of intercept and slope separately.

The correlation coefficient r, between water use and population, obtained from the analysis is 0.83044, and the R squared is 0.68962. Thus from this simple model about 69.0% of the variation in municipal water use can be explained by the change in the population at the inter-city scale.

The same analysis was undertaken on the data for each year. The results (Table 4-2) show that the R squared does not change much with the year, in other words, the correlation between population and municipal water use at the inter-city level remains comparatively stable.

Since the R squared is reasonably high and stable, it may be suggested that population can be adopted as a predictor in forecasting residential water use at

Table 4-2 Results of Regression Analysis Between Population and Municipal Water Use in Separate Years

Years	r	R Squared	Slope(S.E.)
1985	0.880	0.775	60.173 (6.020)
1986	0.883	0.779	66.137 (6.567)
1987	0.893	0.797	70.949 (6.428)
1988	0.892	0.796	77.630 (7.292)
1989	0.873	0.762	78.688 (8.176)
1990	0.874	0.764	81.996 (8.470)
1991	0.867	0.752	149.639 (15.940)
1991*	0.807	0.651	84.672 (11.721)

Note: "*" The city of Shanghai is omitted from the analysis.

the inter-city scale in China. However, a seven-year-long time-series data set may not be long enough to be absolutely confident with the above conclusion, especially if it is to be used in a long-term forecasting. Moreover, thirty-one cities distributed in a country-wide scale, which are definitely not in the same stage in the process of urbanization, should make up much or less this defect according to the time-space process theory (Haggett, et al., 1977). Nevertheless, despite these reservations, the trend in Table 4-2 is consistent.

Some other features are revealed by the regression analysis. Firstly, the slope of the correlation increases with year, from 60.173 in 1985 to 149.639 in 1991 (Table 4-2). This reflects the increase in the per capita residential water use in Chinese cities, which is influenced by the factors that affect the intensity of water use. The reality is that the average per capita residential water use in Chinese urban and town areas increased from 151 litres per person per day (lpd) in 1985 to 172 lpd in 1989. The sudden change in the slope from 1990 to 1991 was mainly caused by the unusual increase in the per capita residential water use in Shanghai city. When the city of Shanghai is omitted from the analysis, the slope becomes more reasonable. Secondly, from the distribution or scattering of the cities around the regression line, a regional diversity of distribution between south and north is very clear. The majority of the southern cities are scattered above the regression line, but the northern cities are below the line except few particular occurrences (see Figure 4.2 and Table 4-3). This shows that the per capita residential water use is higher in the south than in the north of China. It is obvious that the further south one moves in China, the hotter and more humid is the climate, and the more plentiful are the water resources. This feature will be discussed later in this chapter.

Table 4-3 Comparison between the Observed and Estimated Residential Water use in Chinese Cities (in 10^4 m^3)

Cities	Location	Population (10^4 persons)	Observed	Estimated	Residual
Tianjin	NC	430.7	22175	30252	-8078
Dalian	NE	158.0	4093	10658	-6565
Xian	NW	245.0	10497	16909	-6412
Chongqing	SW	232.0	10754	15975	-5221
Beijing	NC	513.9	31212	36232	-5020
Harbin	NE	245.0	12727	16909	-4637
Changchun	NE	146.2	6350	9810	-3460
Taiyuan	NC	139.0	6134	9293	-3159
Kunming	SW	113.0	4315	7424	-3109
Shanghai	SC	753.2	51360	53427	-2067
Lanzhou	NW	105.5	4839	6885	-2046
Urumuqi	NW	98.0	4335	6347	-2012
Chengdu	SW	148.5	7979	9975	-1996
Jinan	NC	126.0	7084	8359	-1275
Xining	NW	62.3	2917	3781	-864
Guiyang	SW	84.0	4505	5341	-836
Shijiazhuang	NC	109.0	6633	7137	-504
Yinchuan	NW	37.8	1525	2021	-496
Hefei	SC	69.4	4046	4291	-245
Nanchang	SC	112.0	7344	7353	-9
Zhengzhou	SC	112.0	7435	7353	+82
Shenyang	NE	317.7	22614	22133	+481
Lhasa	SW	5.0	345	-336	+681
Huhhot	NC	53.8	4385	3171	+1214
Fuzhou	SE	102.4	8794	6663	+2131
Nanjing	SC	218.0	17155	14969	+2186
Hangzhou	SC	113.5	9678	7460	+2218
Changsha	SC	122.0	11901	8071	+3830
Nianning	SE	70.6	9414	4378	+5036
Wuhan	SC	317.6	34220	22126	+12094
Guangzhou	SE	306.0	42184	21293	+20891

Reference: The State Statistical Bureau of China, 1988a.

Note: NE, North-east part of China; NW, North-west part of China; NC, Central-north China; SC, Central-south China; SW, South-west part of China; and SE, south-east part of China.

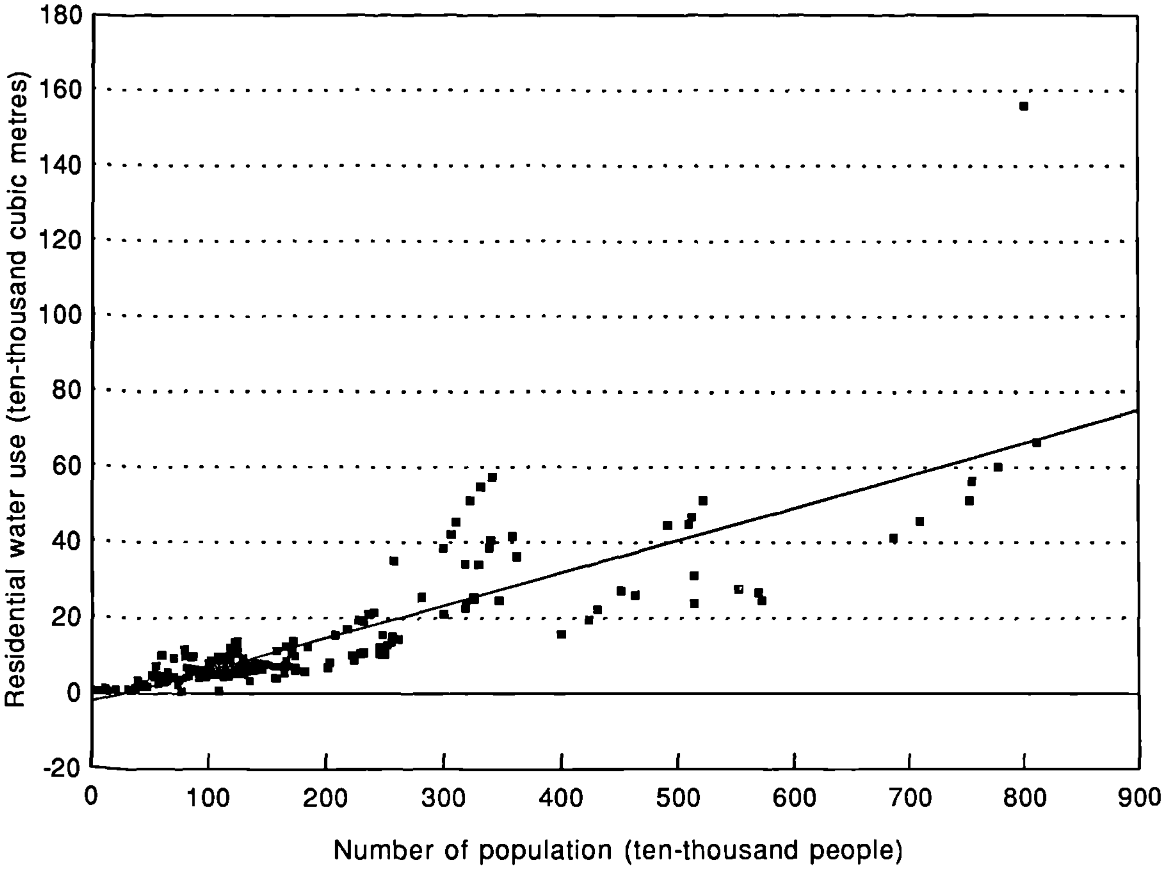


Figure 4.1 Population and residential water use (Inter-city)

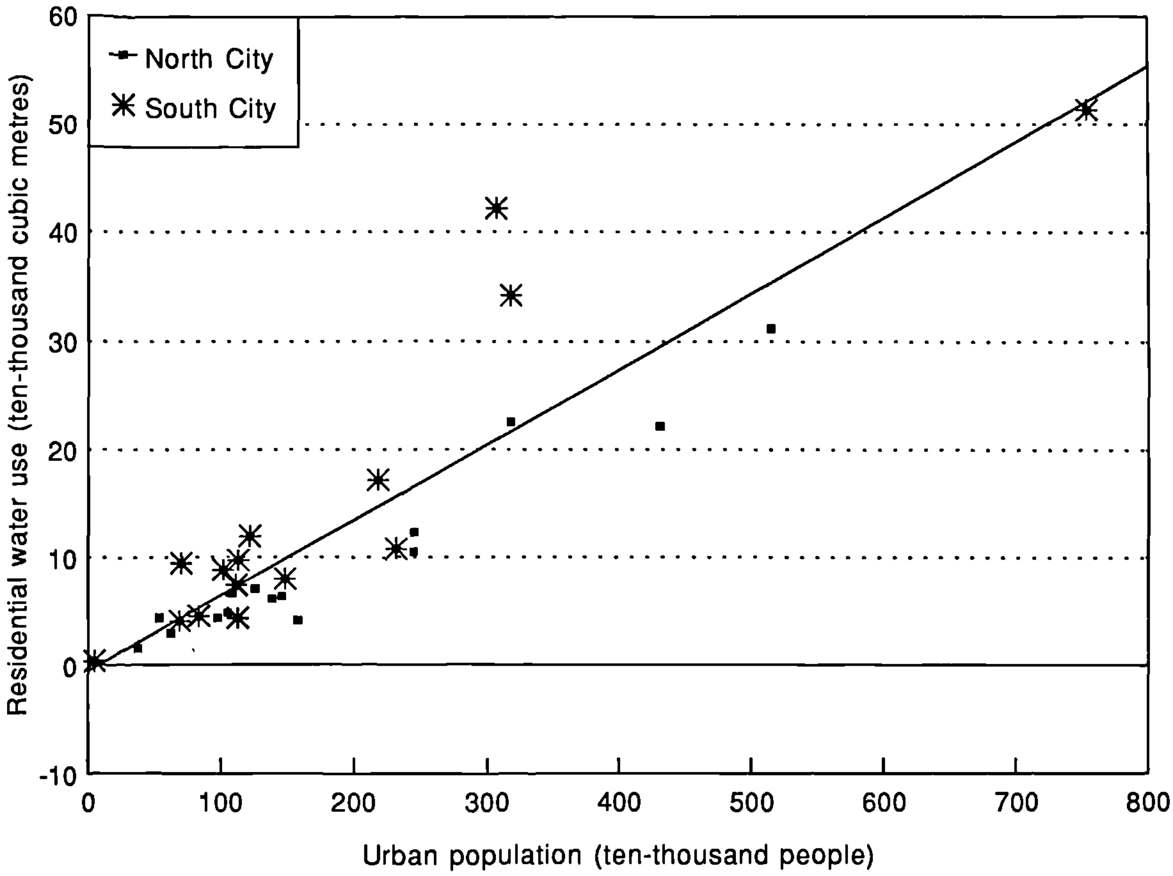


Figure 4.2 Location of the cities and the linear regression line

4.3.2 A City Level Analysis

Lanzhou city is located in the North-west China where the climate is semi-arid. Water used in the city is mainly supplied by the Lanzhou water company, which is one of the largest water companies in the country. Monthly residential water use data and number of people served from 1980 to 1990 are obtained from the company's statistics. Because of the inconsistent classification of residential water use, in which the residential water use data from 1980 to 1985 include commercial water use, while the data of 1986 to 1990 do not, the relationship between monthly residential water use and population served is analysed separately by dividing the data into two corresponding groups, and using the linear regression method. The use of monthly data in the analysis is purposeful, namely to increase the number of cases or observations in the analyses.

The results of the regression analysis from the data of 1980-85 group, and 1986-90 group, are separately presented in Figure 4.3a and 4.3b. The equations obtained from the analysis are:

$$Q_r = \underset{(57.19699)}{32.75260} + \underset{(0.00006)}{0.00050}P_p \tag{4.2a}$$

$$Q_r = \underset{(91.22998)}{-189.62105} + \underset{(0.00009)}{0.00060}P_p \tag{4.2b}$$

in which, the meaning of the variables are the same except for P_p which is in persons, rather than in ten-thousand persons as in Equation 4.1.

The degree of correlation between population and residential water use is not as good as that from the inter-city correlation analysis. The R squared obtained are 0.47413 and 0.44543 respectively for Equation 4.2a and 4.2b. These R squared values are much less than the 0.68962 from the previous inter-city scale analysis.

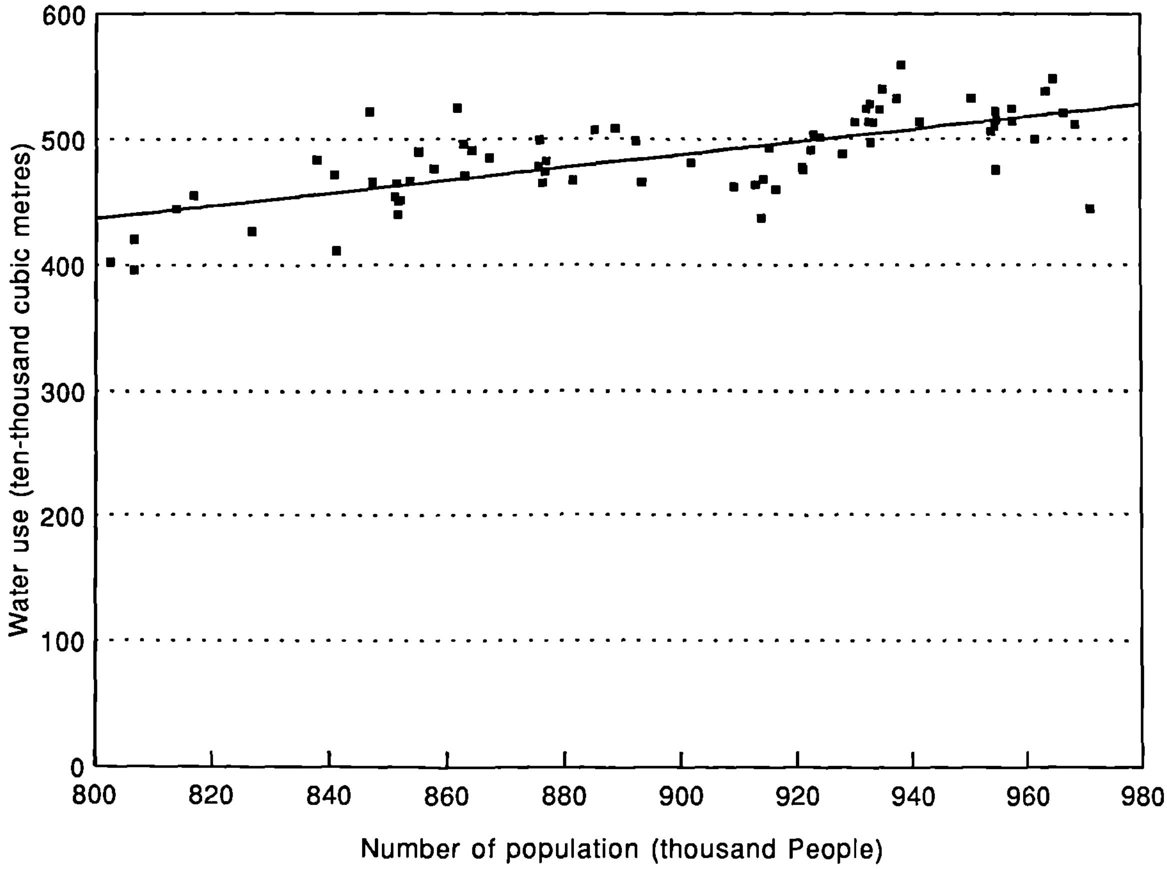


Figure 4.3a Residential water use and population (Lanzhou city)

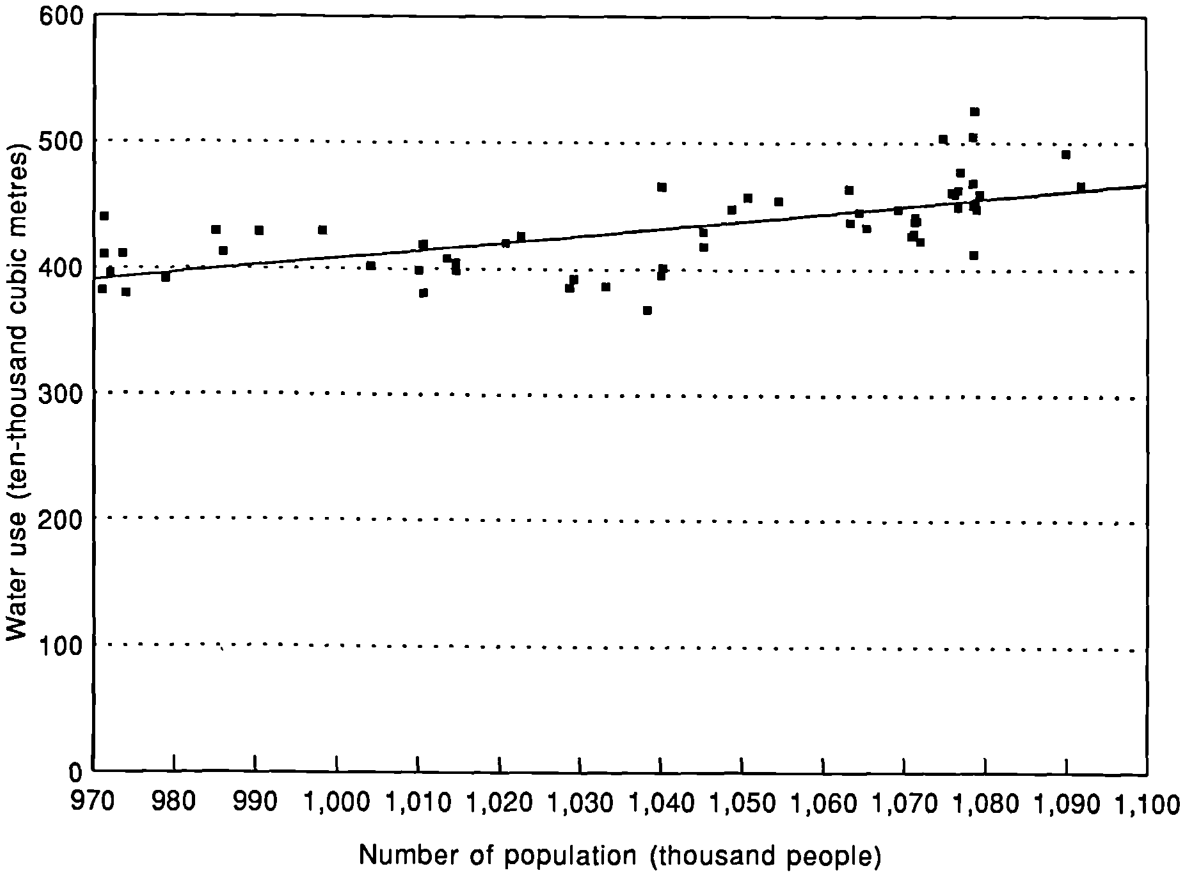


Figure 4.3b Residential water use and population (Lanzhou city)

A yearly cycle of water use from winter to summer exists. This is easily recognized from the time-series display of the residential water use of Lanzhou city (Figure 4.4). It is, perhaps, a consequence of the influence of climate change, occurrences of holidays during the year, and effect of some other variables which change monthly. The monthly residential water use data used in the city level analysis reflect the effects of the variables which change monthly over a year, but yearly data used in the inter-city level analysis do not. These are the major differences between the data used in the two analyses, and may be supposed to be the main reason which explains the lower value of the correlation coefficients in the city level case.

4.3.3 A Household Level Analysis

In this case, 60 households in the city of Xining were chosen for analysis. The 60 households are employed by an organization that owns the housing in which the households reside; and 30 of the households were chosen from apartments in one building. Water use in each house or apartment is measured by an installed water-meter. The data comprises the yearly water use record taken in 1990 based on the apartment and used to prepare the water bill.

The correlation between household water use and the number of people in it was again analysed by using a simple linear regression method. A correlation equation obtained is:

$$\underset{}{Q_f} = \underset{(13.705)}{17.371} + \underset{(3.98)}{10.279}P_f \qquad (4.3)$$

Q_f is the quantity of annual water use of a family in cubic metres; P_f is the number of persons in a family; with the standard error again in brackets.

The result indicates a poor linear correlation between the two variables at the household scale (Figure 4.5). The R squared is only 0.10295; that is to say, only 10.3% of the variation in household water use can be explained by the variation

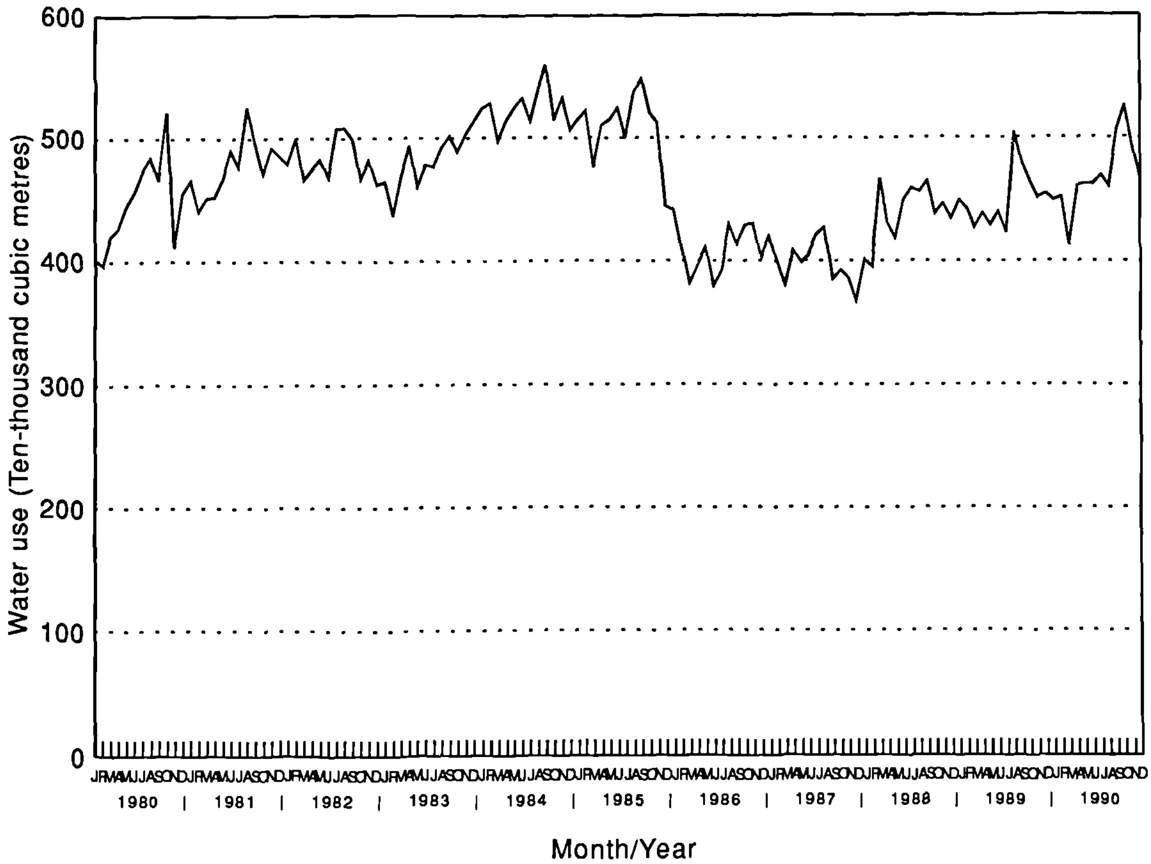


Figure 4.4 Residential water use in Lanzhou

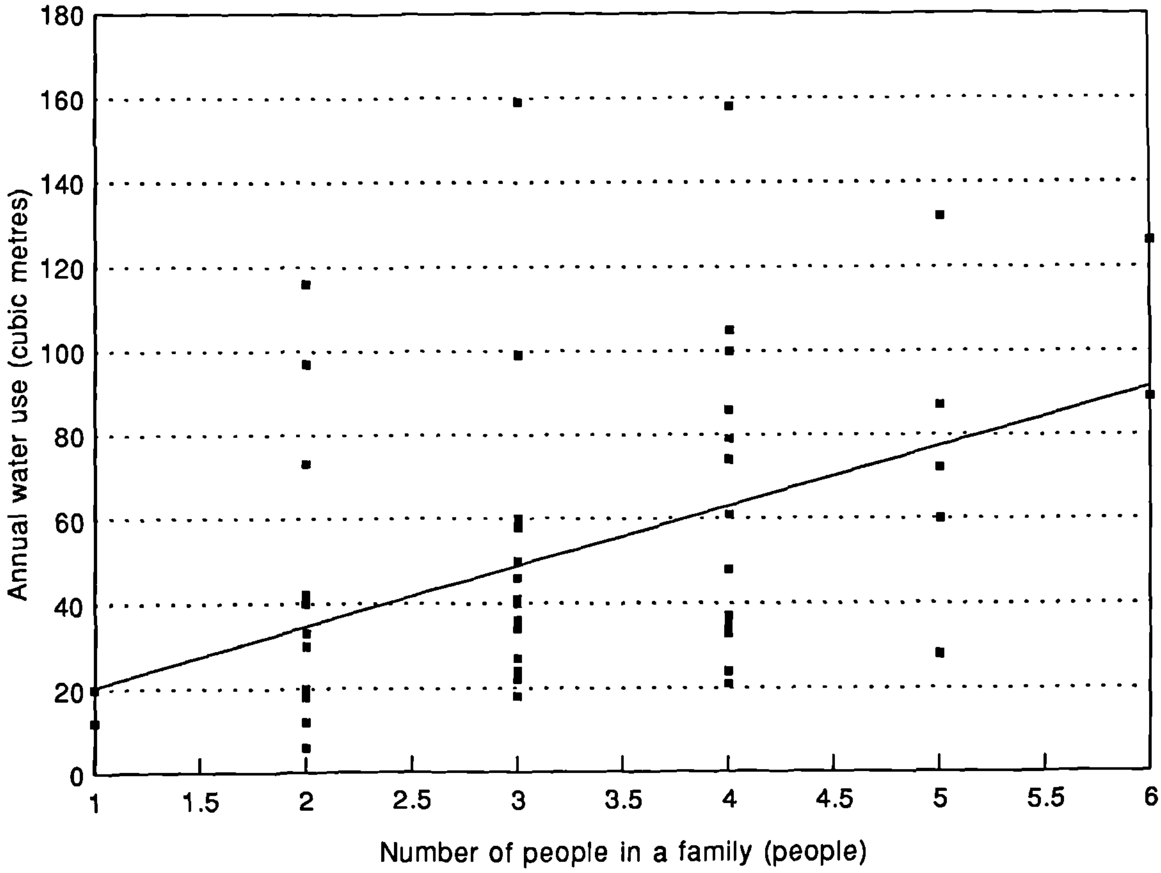


Figure 4.5 Residential water use and population (Households)

in the number of people in the family. It is much less than the R squared in the inter-city scale (0.68962) and a city scale (0.47413 or 0.44543).

The data used in this case is not aggregated at all. Any influence from any factor that may affect household water use will be reflected in the data. Thus population, although it is a factor recognized as influencing residential water use, does not by itself explain the variation of water use very well at this level.

4.3.4 Discussion and Conclusion

The three different scales of linear correlation analyses between population and residential water use resulted in three different outcomes. The strength of the correlation goes down with disaggregation, from the inter-city scale to the household scale.

The result can only be explained by the differences in the data used in the analyses. Where aggregate data is used, obscurity of the effects of some factors will occur. For example, when cross-section data is used on yearly water consumption in a city, the effect of a seasonal change in water demand is obscured; and when total residential water use in a region or a city is analysed, the effects of factors like individual habits, or the number of days a family is not in residence, will not be recognized. At the individual household level, some factors, which may be masked in an aggregated level, may play a significant role in affecting residential water use. The data used in the above analyses represent three different levels of data aggregation so that different strengths of correlation between residential water use and number of population were produced.

It has been argued that the controversy in the water demand literature is directly attributable to the use of aggregate data (Schefter and David, 1985). This is probably true based on the above analysis. However, aggregate data itself should not be disregarded entirely just for this reason and micro data used instead, since micro data itself has its own limitations. Aggregate analysis may yield important insights not available from analysis at the micro level (Darr, et al., 1976). As mentioned before, the effect of a specific factor may be isolated under the assumption that other factors remain the same (Grima, 1972). In reality, factors change simultaneously. Perhaps one method by which this assumption almost becomes true, is by obscuring the influence of other factors by aggregating the data in an appropriate way. The only thing that should be checked and corrected, if controversial results are yielded, is the level and method of aggregation. The rule of aggregation should be to obscure the effect of other factors rather than that of the factor to be analysed. In absolute terms, disaggregating is an infinite process. Therefore, no data can be labelled as without aggregate at all.

There is a minimum level at which the effect of a factor can be obscured. Factors affecting residential water use may be classified into groups; for example, macro factors and micro factors may be identified. Those factors which can have their effects obscured at a micro level, like the number of days that a family is not in residence, can be called micro factors, and vice versa.

While the concept of a level at which a factor has a major impact has been introduced, many factors affecting residential water use can be treated as stochastic variables under some situations. Where a macro level water use problem is concerned, some micro factors may be treated as stochastic variables under the assumption that they do not have a clear pattern of change and hence their influence is indeterminate or stochastic. In this case, aggregate data without identifying the effect of the micro stochastic variables can be used, and the effect of these variables can be ignored during the analysis even if they play a significant role in a micro level analysis. The debate raised by Murdock, et al. (1991), in which it is argued that demographic and socio-economic variables, such as the age of the householder, racial or ethical status, and household composition markedly affect water use, and are often of relatively greater importance than economic, climatic or other physical factors in explaining per capita water use, may be interpreted by the above theory. Their analysis was based on a micro level data set. The variables that they mention, like the age of householder etc., may be classified into the group of micro stochastic variables when a macro level water problem is undertaken.

In brief, factors can be classified into groups according to their main influence in different levels or scales. Some factors have an obvious effect in an aggregated scale, but some have a clear effect in a disaggregated scale. It is difficult to decide which factor is important without referring to the level or scale.

It is clear from the above analyses, however, that population is a better predictor to forecast Chinese residential water use in an aggregated scale and in the long term, than that of a disaggregated scale even in the short term.

4.4 INCOME AND RESIDENTIAL WATER USE INTENSITY

Income or economic level of households is a factor most widely accepted as a determinant of residential water use (Grima, 1972). It is generally agreed that residential water use increases with increases in income or rising of living standards. In various literature, several indicators were used as proxies of income in the association analysis, such as per capita income (Berry and Bonem, 1974), media family income (Khomal, 1976), housing value (Davis et al., 1987). In China, urban housing has no market value because accommodation has been supplied as a kind of public welfare for the urban residents for several decades. Family income is not as common as per capita income as a variable and is not generally used in Chinese economic analysis. Therefore, per capita income is chosen as the proxy of income in the following analysis.

Since income is previously assumed to be a factor influencing the intensity, and not the demand for residential water use, per capita residential water use, rather than total residential water use, is used in the analyses. In the literature, both per capita and total residential water uses were found to be related to income in different analytical studies. Based on different scales and levels of aggregate data, the relationship between per capita income and per capita residential water use is analysed in order to assess or find the impact of income on residential water use in the Chinese urban areas, and the income elasticities as well.

4.4.1 National Scale Analysis

From the Chinese Statistical Year-book of 1988, seven groups of data of average annual per capita income and annual per capita money spent on water usage are available (Table 4-4). This is a statistical compilation of a national-wide investigation, in which 32855 households were randomly chosen from cities and towns all over the country. The households were classified into seven groups according to their income: each of the first two and last two groups incorporate 10% of the total households, and each of the middle three groups account for 20% of the households. A linear regression analysis resulted in the following relationship:

$$\underset{}{W_c} = \underset{(0.052)}{1.15} + \underset{(0.00005)}{0.00093 I_p} \qquad (4.4)$$

W_c is the group average annual per capita money spent on using water in Yuan per person; I_p is the group average annual per capita income also in Yuan per person, with standard errors in brackets. The correlation coefficient r is exceptionally high at 0.99379, and R squared is 0.98762 (see Figure 4.6).

Another correlation equation is obtained by taking the logarithm of both the dependent variable W_c and the independent variable I_p in Equation 4.4.

$$\text{Log}(W_c) = -0.98860 + 0.43759\text{Log}(I_p) \quad (4.5)$$
$$(0.12080) \quad (0.04022)$$

The parameter in Equation 4.5, 0.44, can be regarded as the income elasticity at this scale level (see Appendix A).

Table 4-4 Per Capita Annual Income And Money Spent On Water Using

INCOME GROUPS	Number of Households	Percentage %	Income Yuan/person	Water fee* Yuan/person
LOWER	3285	10	596	1.76
LOW	3286	10	733	1.84
MID-LOW	6571	20	852	1.90
MID	6571	20	991	2.05
MID-HIG	6571	20	1154	2.22
HIGH	3285	10	1352	2.36
HIGHER	3285	10	1734	2.81
TOTAL	32855	100	1012	2.09

Source: The State Statistical Bureau of China, 1987a.

Note: Annual per capita money spend on water can be transformed into per capita annual (or daily) water use by dividing the price of water that does not often change and may be instead by a fixed figure. Therefore, the difference between per capita water use and money spent will not cause the change of the slope in the logarithm form equation, so is the income elasticity.

4.4.2 Inter-city Scale Analysis

In this case, per capita daily water use and per capita annual income in thirty-one cities of China in year 1985, 86, and 87 were analysed using regression analysis. The data used were average values of each city, which were obtained from the Chinese Statistical Year-book. Per capita daily water use, for example, is obtained by dividing the total annual urban residential water use by the number of people served in the city and the number of days of a year (365). The linear regression result obtained is:

$$W_d = 131.12293 + 0.05151I_p \quad (4.6)$$
$$(37.28418) \quad (0.04133)$$

W_d is the per capita daily water use in litres; I_p is the per capita annual income in yuan; with standard errors in brackets. The correlation coefficient r is 0.13173, and R squared is 0.01735. Both are much lower than those in the previous case(see Figure 4.7).

Another equation obtained by taking the Logs of both the dependent and independent variables in the above equation is:

$$\underset{}{Log(W_d)} = \underset{(0.86539)}{1.42716} + \underset{(0.29800)}{0.26983}Log(I_p) \qquad (4.7)$$

An approximate income elasticity of residential water use at the inter-city scale analysis is about 0.27.

4.4.3 A City Scale Analysis

Only eight pairs of data, from 1982 to 1989, of per capita daily water use and per capita annual income in Lanzhou city have been obtained. The per capita water use data is copied from the water company's statistics. The per capita annual income was estimated by the City's Statistics Bureau through sample investigation. The income figure was in real value for each year without any adjustment by the price index. (see Table 4-5).

A linear regression analysis between the per capita daily water use and per capita annual income was undertaken and the following equation was obtained:

$$W_d = \underset{(4.40852)}{131.34703} + \underset{(0.00496)}{0.00284}I_p \qquad (4.8)$$

in which, W_d and I_p mean the same as that in Equation 4.7.

The correlation coefficient r is 0.2278, and R squared is 0.05188, indicating that the two variables are poorly correlated (see Figure 4.8). Another equation at a logarithm base is:

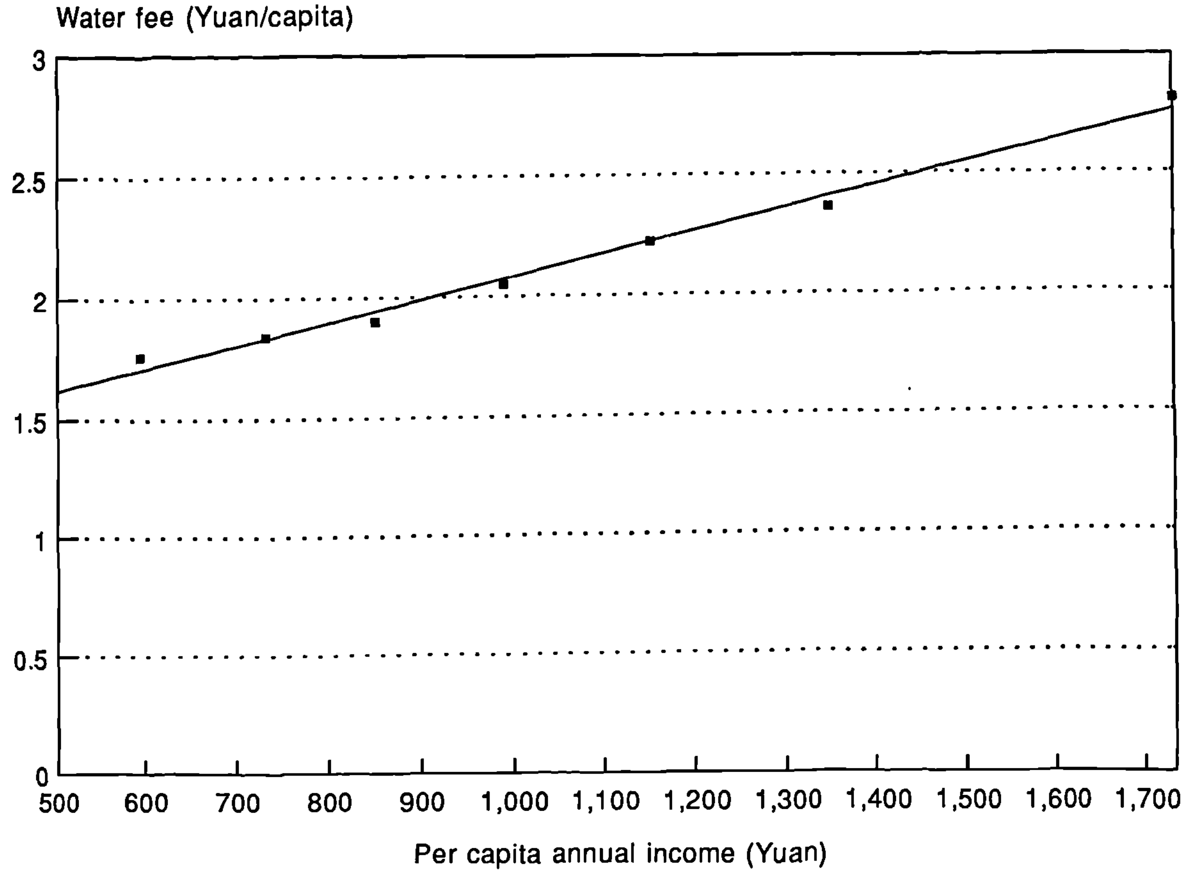


Figure 4.6 Residential water use and Income (National)

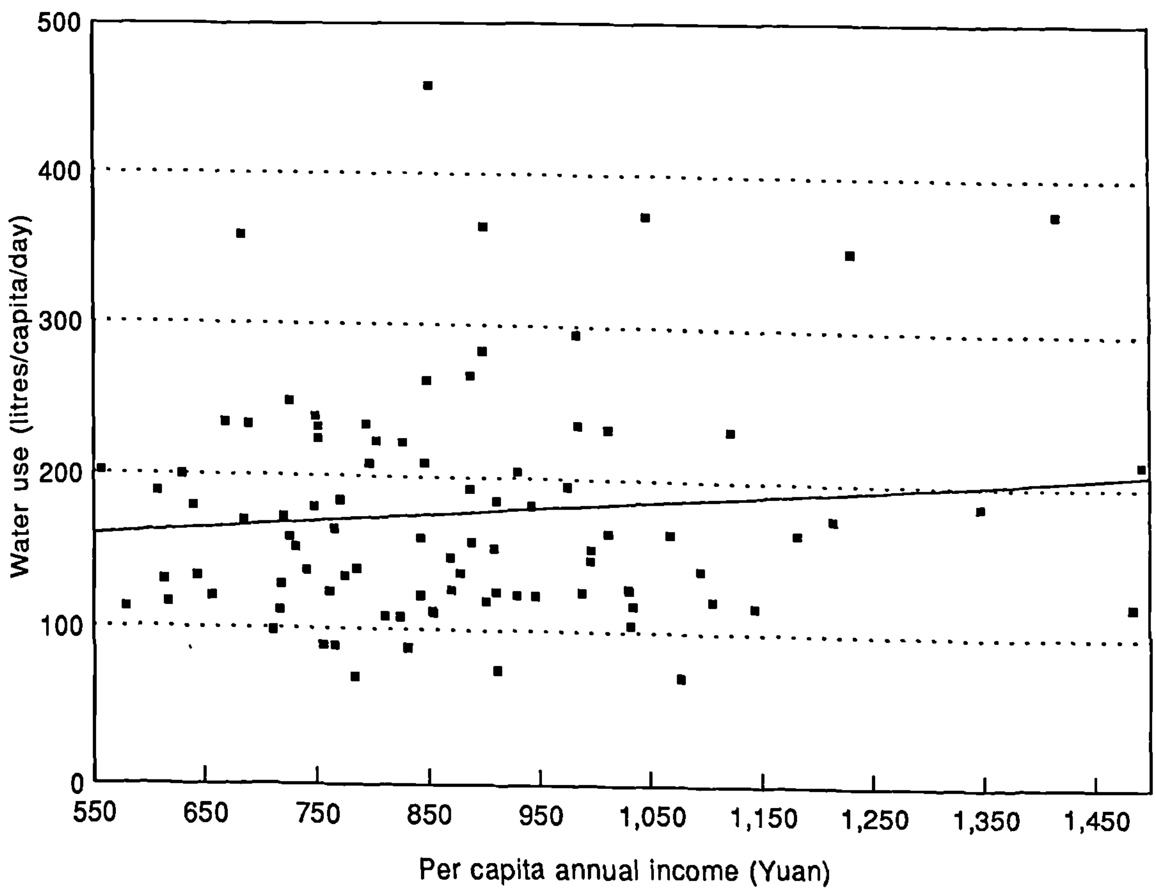


Figure 4.7 Residential water use and income (Inter-city)

$$\text{Log}(W_d) = \underset{(0.09261)}{2.08368} + \underset{(0.03185)}{0.01463}\text{Log}(I_p) \tag{4.9}$$

It gives a very low income elasticity of about 0.01.

Table 4-5 Water Use, Annual Income and Family Size in Lanzhou

Year	Annual income yuan/capita/year	Family size People/family	Per capita water use litres/capita/day
1982	514	4.46	131
1983	530	4.29	135
1984	637	4.13	135
1985	731	3.84	134
1986	942	3.73	137
1987	943	3.71	126
1988	1142	3.63	135
1989	1322	3.46	137

Source: Lanzhou City Statistical Bureau 1982-1989; LWC, 1982-1989.

4.4.4 Neighbourhood Scale Analysis

Sixty households were chosen from a neighbourhood in Xining city. They are the same group of households as that in the previous analysis of population and residential water demand. The relationship between annual per capita income and per capita water use was analysed by using the simple linear regression method. The result is shown in Figure 4.9, and a correlation equation obtained is as follows:

$$W_p = \underset{(3.1808)}{10.47672} + \underset{(0.00147)}{0.00296}I_p \tag{4.10}$$

W_p is the annual per capita water use in cubic metres; and I_p is the annual per capita income in Yuan, with the standard errors again in brackets. The correlation coefficient r is 0.25539, which is also much less than that obtained from the national sale analysis, and R squared is 0.0652.

For the purpose of assessing the income elasticity, the logarithm equation at the individual household level is:

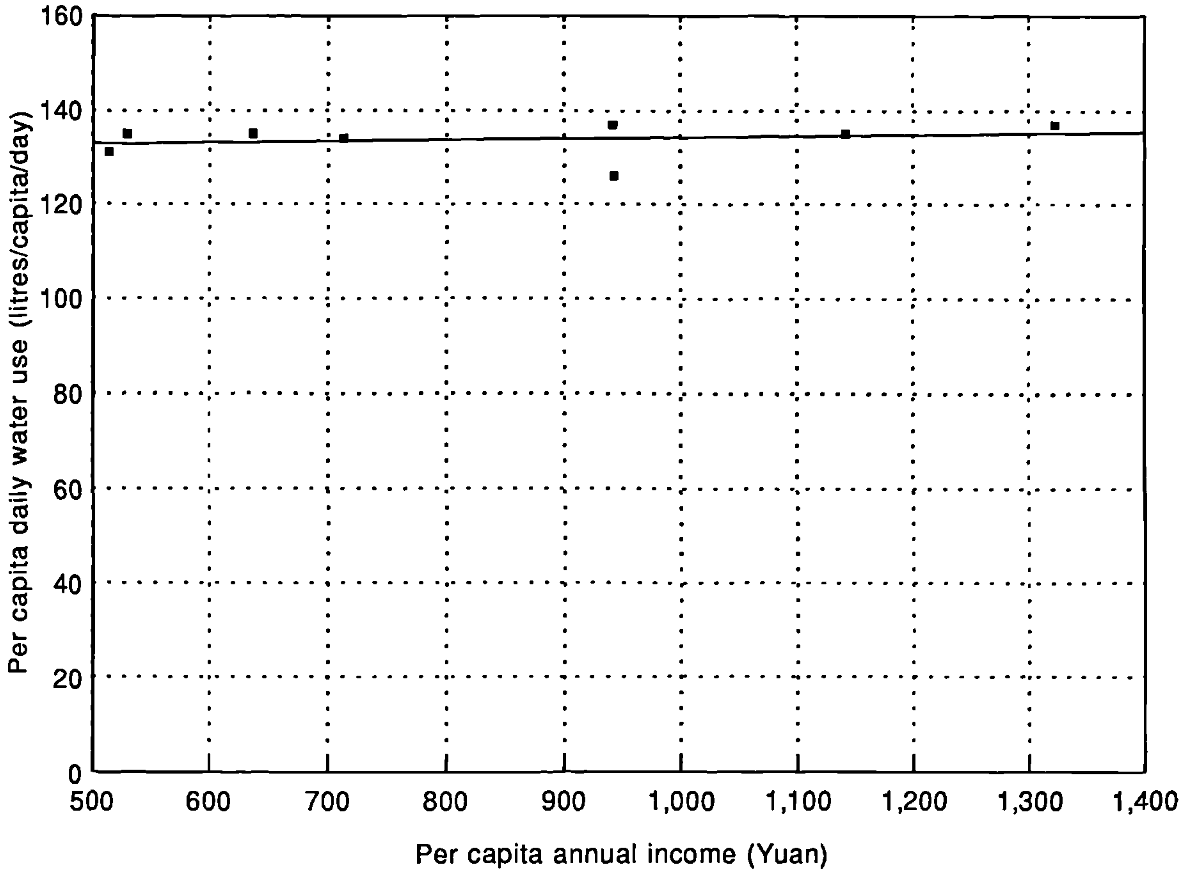


Figure 4.8 Residential water use and income (Lanzhou city)

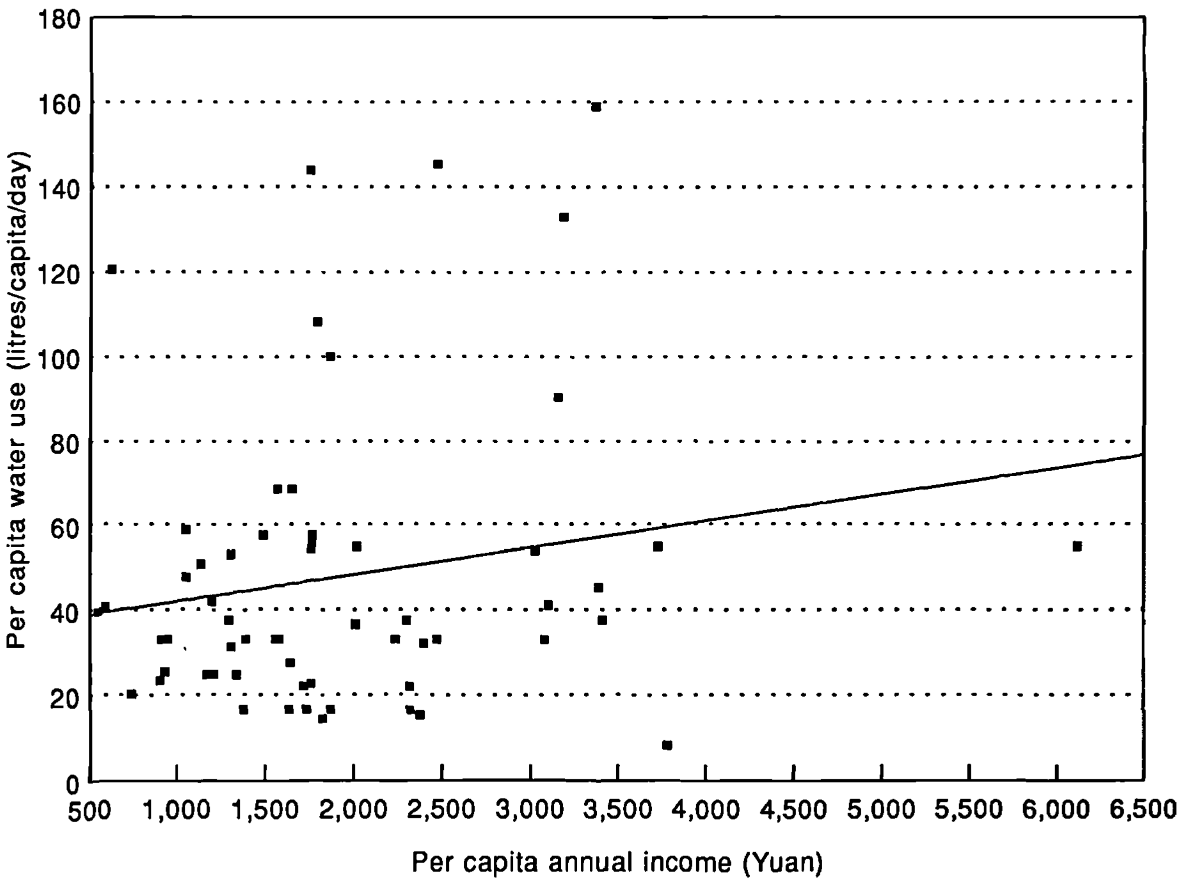


Figure 4.9 Residential water use and income (Households)

$$\underset{(0.52910)}{\text{Log}(W_p) = 0.52864} + \underset{(0.16322)}{0.18451\text{Log}(I_p)} \tag{4.11}$$

The income elasticity in this case is about 0.18, which is also much less than that at the national scale (0.44), and less than that at the inter-city scale (0.27), but higher than that at the city scale (0.01).

4.4.5 Discussion and Conclusion

The above analyses give varied results about income elasticity (from 0.01 to 0.44), and the strength of correlation between per capita residential water use and per capita income (R squared from 0.01 to 0.99). This can be explained from differences in the data used.

The first analysis used very aggregated cross-sectional data, in which seven grouped-averages was derived from 32855 households from cities and towns over the country; with the classification criterion being just income. As discussed in Section 4.2, in this case, except for the effect of income, effects from all other factors must have been greatly obscured because of the aggregation process. Thus, the high correlation coefficient obtained is not unexpected. The income elasticity value of 0.44 should, at least, represent the impact of income on residential water use among the different income-groups under analysis.

The second inter-city case used aggregated data, too; but the classification criterion was not the level of income. From city to city, besides the difference in income, other factors such as climate, water accessibility and the condition of water supply facilities, obviously vary. The actual (inter-city) cross-section water use data is the result of composite effect from the above or even more factors rather than mere income. Thus, when the data is used to analyse the relationship between water use and per capita income, there may be interference from other factors that were not obscured. From this point of view, the data used in this case is totally different from that of the previous one although both are aggregated data. This may be the main reason why the first coefficient is so high while the second is so low. In terms of the coefficient of 0.13, it may be suggested that the variance of income among Chinese cities is not the major reason to cause the fluctuation of per capita water use from city to city. This is true because average per capita income does not change much from city to city in China. Other factors such as climate, water accessibility or water shortage situation may be more responsible for the fluctuation of per capita water use among Chinese cities.

The city case analysis used time-series data, although it is suspected that it may not be long enough for a valid regression analysis, particularly in terms of long-run forecasting. However, the result is worthy of interpretation. In Table 4-5, it can be seen that, from 1982 to 1989, the per capita water use in Lanzhou changed very little, while the per capita income increased, indeed more than doubled. An extreme case is that the per capita residential water use reduced from 137 lpd (litres per capita per day) in 1986 to 126 lpd in 1987. This was mainly due to an accident which happened in August 1987, in which one of the water supply channels was polluted by waste oil discharged from the nearby refinery, thus reducing the water supply. If the data of 1987 is rejected, the correlation between per capita water use and per capita income concluded from the remained seven pairs of data is much improved. The R squared becomes 0.45176, and the income elasticity is 0.02848, which is still very low.

The low value of income elasticity obtained from the short time-series data of Lanzhou city may be due to two reasons. Firstly, the residential water use data is the quantity of water supplied by Lanzhou Water Company rather than that of water demanded by the local residents. Due to the existence of water shortage, water demanded is much more than what has been supplied. According to a report drafted by the water company (1989), residential water shortage in Lanzhou in 1989 was estimated about 21.6 per cent. In other words, only 78.4 per cent of total urban residential water demand could be supplied by the water company. Thus, the trend of increasing demand for water with the increase in income cannot be properly reflected in the data because of the restriction from water shortage. The estimate of income elasticity must therefore have been reduced. Secondly, the income data used had not been adjusted by the appropriate price indices. It was much higher than the real increase in income because of the high inflation rate in China during those years. This would reduce the income elasticity too.

In the household scale analysis, the less aggregated data used reflect the effects from many factors besides that of income. The data were chosen from a micro scale, so the reader should not be surprised to get low values for the correlation coefficient and income elasticity, for a similar reason as discussed in Section 4.3.4.

The above analyses again reveal that the method of classification and aggregation is important in causing obscurity of effects of factors in the correlation analysis. One way of data classification and aggregation is to obscure the influences of all factors except for the factor that is to be analysed. Under this condition, factors in which their influences were obscured would be treated as constant, and the relationship between the dependent variable and the only independent variable could be revealed exactly.

It may be suggested that income has some effect on the per capita residential water use, and can be used as a predictor in forecasting residential water use for Chinese urban areas; but it is more reliable to use it in some properly aggregated ways. This may be explained by the fact that income has a socially common effect on the residential water use. That is to say the real income of a household may have a little effect on its water use, but the average income of an area or a country may affect the average per capita residential water use much more. It may also be suggested that income affects the residential water use in the long-term. This can be explained by the fact that the acquisition of water-using appliances is a long-term adjustment; the year to year increase in real income has only a limited effect on year to year increase in residential water use (Grima, 1972).

4.5 PHYSICAL FACTORS AND RESIDENTIAL WATER USE INTENSITY

Physical factors, particularly climatic variables, have been identified as influencing residential water use by many research studies, mainly carried out in America. Various proxies for climatic variables have been used and combined into different residential water demand forecasting models, such as precipitation (Reid, 1971), average annual precipitation and annual temperature (Stevens, et al., 1992), potential evapotranspiration minus precipitation (Nieswiadomy and Molina, 1989; Agthe and Billings, 1980), summer season moisture deficit (Davis, et al., 1988), days with precipitation (Whitford, 1972), and so on. A commonly accepted opinion is that climatic variables mainly affect outdoor water use, i.e. lawn sprinkling. The IWR-MAIN model (Davis et al., 1988), for example, only include climatic variables in the summer water use sector. In Chinese urban areas, as mentioned before, outdoor water use does not account for a substantial part, and in most cases it is almost negligible. Then, a question required to answer is whether or not climatic variables significantly influence the Chinese urban residential water use.

In Section 4.3 and 4.4, it was mentioned that the diversity of per capita water use between Chinese cities may be accounted for by physical factors, i.e. climate, and availability of water resources. And in Section 4.3.2, the annual fluctuation of residential water use was also partly seen to be influenced by climatic variation. Thus another question is whether or not these supposed explanations are correct. The following analysis is intended to answer the above questions.

4.5.1 Inter-city and Inner-city Scale Analyses

In the analysis, the data used is a composition of cross-section and time-series data of thirty-one Chinese cities for the years 1986 and 1987, obtained from the Chinese Statistical Year-book. Two independent variables, annual total precipitation and annual average temperature, were adopted. The relationship between per capita residential water use and the two variables was analysed using the SPSSx multivariable analysis procedures. The result is presented in Table 4-6 and a multiple linear equation obtained is:

$$W_d = \underset{(22.14)}{54.48} + \underset{(0.024)}{0.065}R_y + \underset{(2.298)}{5.471}T_y \tag{4.12}$$

in which, W_d is the annual average per capita daily residential water use in litres; R_y is annual total precipitation in millimetres; and T_y is the annual average temperature in degrees centigrade.

The multiple r is 0.685, and R squared is 0.470. It may be said that about 47% of the spatial variation of per capita water use in Chinese cities is caused by the spatial differences in annual precipitation and annual average temperature.

Table 4-6 Result of the Multiple Analysis between the Climatic Factor and Residential Water Use

Variable	B	SE B	Beta	T	Sig T
R_y	0.065477	0.024482	0.388900	2.675	0.0098
T_y	5.471021	2.297702	0.346232	2.381	0.0208
Constant	54.475157	22.135144		2.461	0.0170

A similar analysis was undertaken for Lanzhou city using two years of monthly data. It seems that there was no strong relationship between monthly average per capita water use and the other two correspondent variables. No variable was included in the multiple equation by the stepwise procedure. Even with Pin (0.15), no variable was included. This is to say the seasonal fluctuation of rainfall and temperature do not affect the monthly average per capita residential water use very much in the city of Lanzhou. So the yearly cycle of water use mentioned in Section 4.3.2 must be the effect of some other factors rather than the monthly fluctuation in temperature and rainfall.

4.5.2 Discussion and Conclusion

From the above analyses, a conclusion may be drawn that climatic factors, i.e. temperature and precipitation, mainly cause the variation in per capita water use over a large space; but that they do not account for the intra-regional annual nor even monthly fluctuations. This is perhaps the reason why Grima classified them into the group of "Macro-scale or Inter-regional Factors" (Grima, 1972). However, according to Miaou (1986), temperature and rainfall have obvious effects on the fluctuations in daily urban water use, which were combined into his model for short-term daily urban water use forecasting. It seems that the above two conclusions are contradictory to each other. Nevertheless, the contradiction can be explained by the differences in data used in the analyses.

What Miaou described was the day-to-day fluctuation in urban water use, which was treated as a stochastic process by him. His model was to serve a short-term, i.e. less than two weeks, daily urban water demand forecasting. He found that the daily variation of climatic variables, i.e. temperature and rainfall, were responsible for the daily fluctuation in urban water use. Under the title of long-term water use forecasting, what this research tries to reveal is the causes of the change in per capita water use over a long-term, or a large scale, but not the short-term, or daily, stochastic variation of urban water use. When annual, or monthly average data is used, both the daily fluctuations in water use and climatic variables will be partly or even totally obscured. This is a result of data aggregation as discussed at the beginning of Part one and in previous sections of this chapter. That is why the conclusion from the analysis by using annual and monthly average data is different from that obtained by Miaou (1986) who used daily urban water use and climatic data. However, in terms of long-term forecasting, the daily fluctuation in water use is not very important if it can be recognized as a stochastic variation and lacks a clear trend, except that it may be used to estimate the maximum daily water use.

If a model is built up by analysing a local data set, a city for example, climatic variables may be ignored in considering a long-term residential water use forecast for the same local area. This argument is based on two reasons. Firstly, the function of climatic variables on the annual average per capita residential water use is not significant from the inner-city scale analysis, which may be explained by the fact that the change in climate from year to year is not very dramatic. Secondly, in general, there is no very clear trend for the long-term change in climate, or it is too difficult to tell, except for an estimated range of its fluctuation that can be obtained from statistical analysis of historical data. Anyway, if a model is built up based on macro scale, or inter-regional cross-section data, it is better to take climatic variables into account, in which obvious functions of climatic variables can be found, like the result obtained from the inter-city analysis.

4.6 FAMILY SIZE AND RESIDENTIAL WATER USE INTENSITY

Family size, or the number of persons in a household, may influence the per capita residential water use. If more persons live, cook and wash clothes together, they will save water compared to the situation in which they do these things separately. In other words, household water use should rise slower than the number of residents, other things being equal. It may be called the economy of scale of this variable. This is different from the function of this variable used in the IWR-MAIN model (Davis, et al. 1988), in which the variable is assumed to linearly affect the household's water use rather than the per capita use. If a linear equation is built up between the per capita water use and family size, the relationship between household water use and family size will be non-linear, or the equation obtained will be to the second power of the family size. This is unlike the linear function of family size in the IWR-MAIN model.

Howe and Linaweaver (1967) has recognized the household size effect by including the number of persons per dwelling unit as an independent variable in their theoretical domestic demand model, but failed to include it into the equation of best fit because of an insignificant result revealed by their case study. Later, results obtained by Morgan (1973), Danielson (1979), and Darr, et al. (1976), who used micro-data in their analyses, revealed that the per capita residential water use decreased with the increase in the number of people living in a family.

In this study, three samples were used to test the above hypothesis for Chinese residential water use. One is to use the group average data from a nationwide survey, the second is a city's time series data, and the third is individual household data from a neighbourhood investigation.

4.6.1 National Scale Analysis

The same data source as that of Section 4.4.1 was used, except for the classification criterion. Now, the 13300 households were classified into five groups by the number of persons of each household. In general, they are: 1-2 person households, three person households, four person households, five person households, and six and more person households. In each group, an average mean family size was calculated (see Table 4-7). By using a linear regression analysis for the five pairs data of family size and per capita residential water use, a regression equation is obtained as following:

$$W_d = 52.76 - 5.63P_f \qquad (4.13)$$
$$\quad (6.86) \quad (1.59)$$

W_d is per capita daily water use in litres; P_f is the number of person of a household. The correlation coefficient r is -0.8985, and R squared is 0.807. The two-tailed significant level is 96.2% that the two variables correlated to each other (see Figure 4.10).

Table 4-7 Family Size and Per Capita Residential Water Use

Groups	Family Size persons/family	Annual Water Fee yuan/person/year	Daily Water Use litres/capita/day
Two person	1.96	3.48	47.67
Three person	3.00	2.16	29.59
Four person	3.99	2.04	27.95
Five person	4.98	1.80	24.66
Six and more	6.32	1.44	19.73

Source: The State Statistical Bureau of China, 1987a.

4.6.2 A City Scale Analysis

From the Lanzhou City Statistical Year-book, the estimated average number of people in a household, from 1982 to 1989, are available (see Table 4-5). For the reason mentioned in Section 4.4.5, the data of the year 1987 is rejected. The remained seven pairs of data of per capita water use and family size was analysed by using the simple linear regression method. An equation obtained is:

$$W_d = 151.148 - 4.136P_f \qquad (4.14)$$
$$\quad (6.232) \quad (1.576)$$

The meaning of the variables are exactly the same as that of Equation 4.13. The obtained correlation coefficient r is 0.761, and R squared is 0.579, with two-tailed significance at 95.5% level (see Figure 4.11).

4.6.3 Household Scale Analysis

The sixty households used in Section 4.3.3 and 4.4.3 were used again here to analyse the relationship between per capita water use and family size. A similar linear equation obtained as Equation 4.13 is:

$$W_d = \underset{(12.83)}{59.15} - \underset{(3.73)}{4.53}P_f \qquad (4.15)$$

The variables' explanation are the same as in Equation 4.13.

The correlation coefficient r obtained at this scale is only -0.16, R squared is merely 0.025, and at 77.1% two-tailed significant level that r is not zero (see Figure 4.12).

4.6.4 Discussion and Conclusion

From the results of the above analyses, it may be said that family size has a negative function on the intensity of residential water use. The per capita water use decreases when the family size increases, and vice versa. The less aggregated the data used, the looser the strength of the correlation. Perhaps it should be noted that the small size of samples may contribute to the higher correlation coefficient in the national level and city scale analyses. At the household level, however, family size may not be a reliable predictor of per capita water use because both the R squared and the t-test significance are so low. At a proper aggregated level, its function can be obviously revealed. This may also be explained by the occurrence of obscurity caused by aggregate data.

Family size may be recognized as a micro factor. If there is no clear trend of its change in the future, it may be treated as a stochastic variable as well in a long-term macro scale forecast. However in China, the average family size is decreasing because of the family planning policy implemented since the beginning of 1970s. Therefore, it is better to take this variable into account when forecasting long-term water demand for Chinese urban areas.

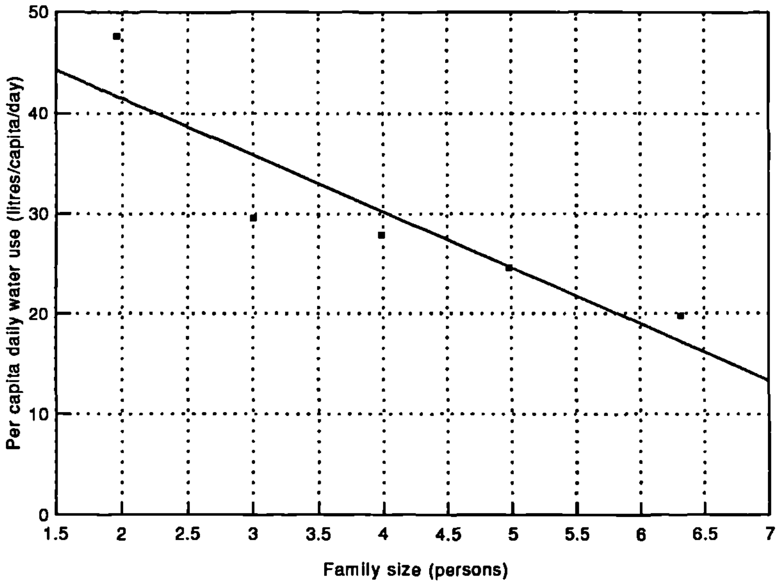


Figure 4.10 Residential water use and family size (National)

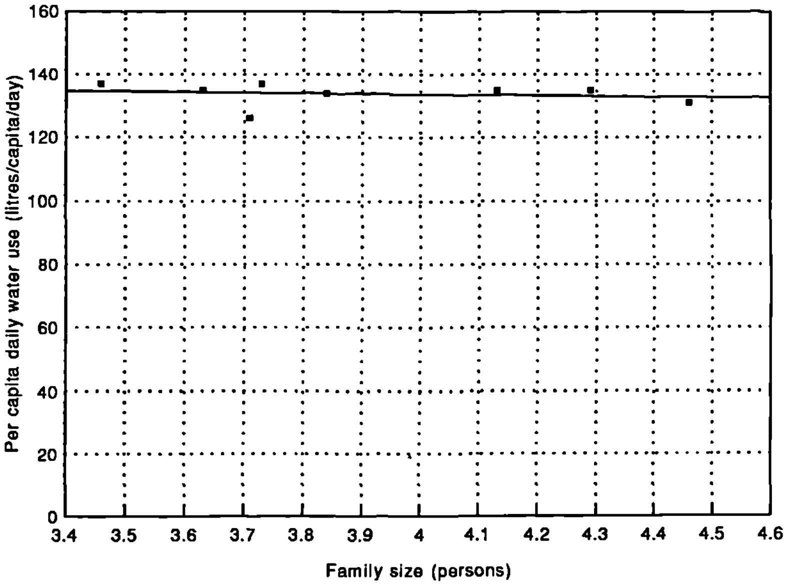


Figure 4.11 Residential water use and family size (Lanzhou city)

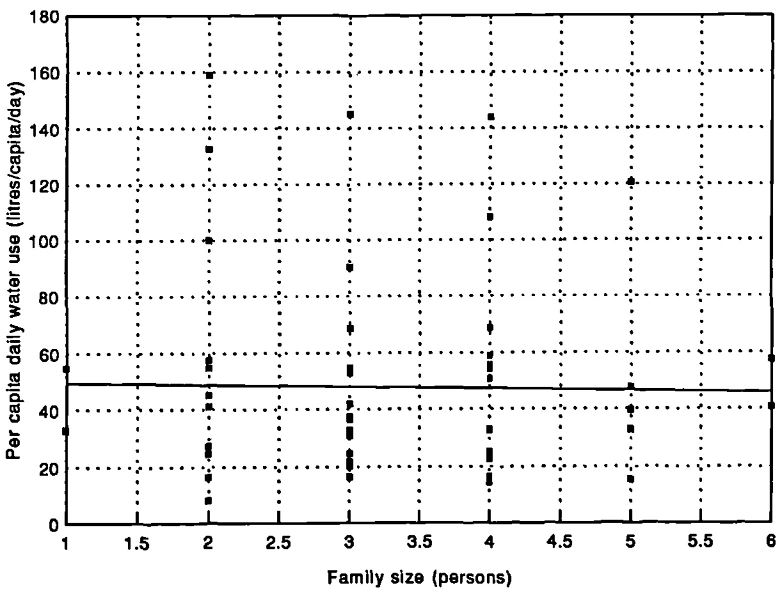


Figure 4.12 Residential water use and family size (Households)

4.7 FUNCTIONS OF OTHER FACTORS

Apart from the factors analysed, other factors such as the water shortage restriction, conservation movement, level of urbanization, water price, water bill collection methods, etc. may have some influence on the Chinese urban residential water use. Due to the shortage of detailed data, it is impossible to analyse their functions by using the same method as that used previously. However, a general assessment is necessary.

4.7.1 Water Shortage Restriction and Conservation

As mentioned before, water shortage has become a serious problem in Chinese urban areas. Nowadays, more than two thirds of Chinese cities face this problem. Restricted by water shortage, various measures to reduce water use have been taken by the management of water supply organizations consciously or unconsciously, such as installing water-meters, reducing the pressure in the water distribution system, encouraging people to save water by education, and so on. Water shortage greatly restricts the increasing demand for residential water use. This may be the major reason for the very low income elasticity, less than 0.015, obtained from the city level income analysis in Section 4.3.3.

From a country-wide perspective, cities that have the lowest per capita residential water use are those that are most infamous for their water shortage, like Qiandao, Darlian, which are located in the coast area. In Darlian, for example, per capita residential water use is less than half of that in Shenyang, although they are located in the same province and not far from each other. Even in one city, unbalances in water shortage may cause big differences in per capita residential water use. In Lanzhou city, for instance, per capita residential water use of 1986 in Chengguan district was 116 litres per capita per day (lpd), while in Xigu district it was 223 lpd. These are based on average data for the district. If individual household, or a small area is concerned, the difference becomes much larger. Taking Lanzhou for example, in 1988, its average per capita residential water use was 131 lpd; but in the most serious water shortage area of the city, the per capita use was only 15.6 lpd (Lanzhou Water Company, 1989).

Water shortage restrictions, although it is difficult to estimate how much water is reduced by it, is definitely an important force influencing residential water demand. This author views residential water use as something which an individual household or person becomes accustomed to. Personal custom is very flexible with the change in water environment. All researches are carried out under the assumption that the water environment is unlimited and comparatively fixed, and water itself will not cause the change in human behaviour in a short time. However, when serious water shortage occurs, this assumption does not hold. Water shortage not only changes people's behaviour in using water, but partly or totally offsets the increased trend caused by some factors like income, family size, population increase, and so on.

When forecasting residential water use to the future, it is necessary to estimate whether or not the water shortage restriction will remain the same, or become looser or more serious. It is better to estimate the impacts of the different situations. Most long-term forecasts were based on historical water use data which are extrapolated into the future. If this assumption is used for some Chinese cities, this is equivalent to assuming that the water shortage situation will not change. However, if the water supply situation is greatly improved, for example by transferring water from another watershed, the water use behaviour of people may change a great deal so that it cannot be conducted from an investigation of their past experience. Nevertheless, it is not easy to greatly improve the urban water supply situation in terms of both economy and environment, especially for big cities of China. Therefore, the problem of water shortage will not be easily resolved, or it may become worse for some Chinese cities in the foreseeable future. That is the major reason for the necessity of water conservation movement which has become an increasingly more important strategy to solve the Chinese urban water problem as discussed in Chapter Three.

Conservation measures, as alternatives of water supply, have been suggested for consideration in forecasting water use, like those reviewed in Chapter Two. In forecasting Chinese urban residential water use, however, it is not easy to take the conservation measures into account. This is because: firstly, residential water use is much less than what is considered to be satiated in most Chinese cities so that it is questionable whether the trend of increasing water use will be diverted by the conservation movement; secondly, water waste behaviour in urban daily life is not very serious because of the comparative underdevelopment of urban water supply facilities and the restriction of water shortage; and thirdly, water price has not been used as a measure to influence residential water demand so that it is impossible to judge what its role is at this stage. Therefore, at the moment, the effect of water conservation measures that can be considered in forecasting residential water use for Chinese cities may be only those caused by the adoption of water-saving facilities, such as new-style toilets, water taps, etc.

4.7.2 Price of Water and Charge Collection Method

Among all the factors which are recognized as affecting residential water use in the literature, price of water is the factor which has attracted most studies. This is because it is thought to be a key issue for effective management in a market economy. However, in China, a planning-dominant economy has been in operation for over forty years. Although the market economy is becoming more popular in China today, water is still a kind of public good rather than a commodity. Water price, which possibly can have a function in affecting residential water use, has not been used as a measure to influence urban residential water demand. The price of water in some Chinese cities has been increased during the past few years, but it was much less compared to the price increase of other things, or the inflation rate. Thus, it is difficult to estimate the function of water price and its elasticity under this situation.

Another issue contributing to the problem is the method by which water bills are collected. The water fees from households are not collected directly by the water companies from most Chinese urban residents. The organization which owns the house that a household lives in is responsible for the water fee collection. In Chinese urban areas, each unit such as a factory, university, company, institute, etc., is responsible to supply accommodation for its employees. The water fee collector is normally the unit that the resident works for. For convenience, some units may pay the total water fee consumed by their employees and their families to the water company instead of collecting them household by household, although a water-meter has been installed in every household by requirement. There are some other convenient ways of collecting a water fee by population or household units, such as to charge a fixed sum for each head for a fixed period. In these cases, water price may have a zero price elasticity unlike what would normally be expected.

4.7.3 Level of Urbanization and Culture-Originated Causes

The level of urbanization is recognized as a factor influencing residential water use, as can be seen by comparing per capita water use among cities that have different scales, or population size. It was found that the larger the urban areas, the higher the per capita residential water use. This has been generally proven for Chinese cities by Yang, Ren, et al. (1984). They found that, in China, per capita residential water use in small and mid-size cities (with residents less than one million) is much less than that used in big cities (which have more than one million residents). On average, water use in the former was found to be about half of the latter. It was mainly explained by the fact that big cities have more public facilities and organizations which consume water.

Another reason, in terms of the Chinese situation, may be the comparatively underdeveloped urban economy and less developed public water supply facilities in small and mid-size cities. From an analysis of thirty-one provincial capital cities in China, it was found that, in 1990, the average per capita residential water use of each city was not significantly related to its population, although the population size of the thirty-one cities vary from 123 to 8117 thousand people. The major cities of the country and capital cities of provinces are the most developed urban areas of China in terms of economy and infrastructure. Therefore, the second reason raised above may be more important for the explanation of the influence of urbanization. Reid (1971) combined the level of urbanization, which is represented by urban population, into his macro urban water demand forecasting model. However, according to the above analysis, at least for the Chinese big cities, it is doubtful whether it can be assumed that urban population is a good indicator of urbanization.

Culturally related factors may have some effects on residential water use. They mainly include racial and ethnic status, regional originated customs, etc. From one household to another with different racial status, or ethnic status, or which has a different regional background, it may be possible to find different customs of water use. Treating a city as a whole, which is composed of households with different racial and ethnic status, and different regional-originated customs, future residential water use of the city will be decided less by these variables because they are less changeable compared with some other variables. In Chinese urban areas, racial and ethnic status are comparatively simple or pure, regional-originated customs are varied but tend to become unified with time in one city. In a long-term and macro level urban water demand forecast, these factors may be treated as stochastic variables if it is not clear that these status will have any major change in the future. This greatly depends on the situation of the city being studied.

There are some other factors that have not been discussed in the analysis, like occurrence of holidays, number of days that a family is not in residence, personal habits in using water, age of the head of household, etc. They definitely belong to the category of micro factors, according to the classification. From a long-term perspective, it is possible to treat them as stochastic variables too, if there is no obvious trend of change. This is equivalent to assuming that they just cause short-term fluctuations in residential water use, and thus will not have much effect on the long-term trend in residential water use. Therefore these factors, including all the factors discussed before that were recognized as having no clear trend in influencing future water use, will not be considered in building up a long-term residential water use forecasting model. This rule could be adjusted by the situation of the city or region to be studied in each case.

4.8 SUMMARY

In this Chapter, factors that are thought to have some effects on Chinese urban residential water use were analysed using statistical quantitative methods or by qualitative assessment. The results revealed that the relationships between a factor and water use, which are derived from analyses by using different data that represent different aggregate levels or scales, are quite different from one another. Therefore, it is first necessary to decide the scale or level at which a study is going to operate. Only then can the factors that need to be considered be decided. If a study is going to carry out a long-term water demand forecasting model for a city, it is unnecessary to take micro stochastic variables into account. If a short-term variation of residential water use from one household to another is the purpose, some factors that are treated as micro stochastic variables in a long-term macro study may play significant roles, and some macro factors, such as income, may be found insignificant, like the result obtained by Murdock, et al. (1991).

From this point of view, factors that affect residential water use can be generally classified into two categories according to the level that they represent: macro factors and micro factors. Population, average income, annual average temperature and rainfall, level of urbanization, water shortage restriction and conservation may be classified into the category of macro factors; daily temperature and rainfall, family size, age of the householder, ethnical status, number of days that a family is not in residence, and so on, may be put into the category of micro factors. Stochastic variables are those variables that do not have a clear trend of change over time, which can only be decided during the study process for each special case. It is unnecessary to keep all the micro factors out of analysis when working on a macro issue. It is only necessary to do this when the micro factors can be treated as stochastic variables as well, or there is no clear trend of change in these variables in a foreseeable future.

Finally, based on the above analysis, it may be generally suggested that for long-term city-wide water demand forecasting in China, the significant factors that should be concerned are: number of urban population, average per capita annual income, average number of people in each family, and water conservation policy, in which the water conservation policy may include the measures of management, technological improvements in household water-using facilities, and education or propaganda for encouraging water-saving.

Chapter Five
INDUSTRIAL WATER USE

5.1 INTRODUCTION

Industry is the largest user of water in the Chinese urban areas. On average, it consumes about 70% of water supplied by the whole of the national urban water facilities. From city to city, the ratio varies considerably. For example, in the thirty largest cities of China listed in the Chinese Statistical Year-book 1987, excluding Lhasa city where there is little industrial activity, the ratio varies between 35% to 78%.

Water is used for various purposes by industry. Water use greatly depends on the technology used and productive process adopted in each kind of industry. In general, the usage of water in industry can be broken down into three categories: cooling and condensing, processing, and air conditioning. Cooling and condensing takes about two-thirds of industrial water use while the other two categories take only one-third. In addition, industry is also a major producer of liquid wastes because little water is actually lost in the production process. Water loss is generally less than 10% of the total water intake, or even as low as 1% for some purposes of industrial water use such as cooling.

There are some factors that can be easily recognized as having a potential influence on industrial water use. They are: the scale of industry, structure of industry, recycling of water use, technology used in the productive process, price of water, policies and regulations about water using, and so on. For the reason given previously, the scale of industry is recognized as the factor affecting the demand for industrial water. The other factors can be treated as just influencing the intensity of industrial water use. In the following sections, the relationships between industrial water use, either demand or intensity, and the factors affecting it are analysed in order to see whether or not these factors, or variables, are significant in influencing urban industrial water use in Chinese cities.

5.2 INDUSTRIAL SCALE AND INDUSTRIAL WATER USE

In a general sense, there is no doubt that the larger the scale of industry, the more the water is needed; or the more industries there are in an urban area, the more the water is demanded. Therefore, the industrial water use should be directly proportional to the scale of industry, other factors being equal.

Several measures may be adopted to indicate industrial scale, such as gross value of production, total production in weight, length or number of products, number of employees, raw materials consumed, and so on. All the above measures have been used in the literature, but only the gross value production has been used in studying the Chinese industrial water use (Ren and Jiang, 1984; Wang and Mu, 1991).

When they are used to build statistical quantitative relationships with industrial water use, each of the above measures has its advantages and disadvantages. An important advantage of the parameters of gross value production, number of employees, and raw materials consumed, is that they can be used to describe a very aggregate situation, for example, whole industries of a city, region, or country, which includes various types of industries. They can also be used in disaggregated studies. However the gross value of production is problematic because of the changeable price of industrial products, although the price index can be used to adjust the effect of inflation or deflation. The number of employees can only show the general scale of industry. Under some situations, it may fail to reflect the exact scale of industry. For instance, in China, many national-owned factories employ more workers than they need because of overmanning and due to the economic system; but in the newly emerged private-owned and foreign-invested or joint-venture companies and factories, over-employment does not necessarily occur. With the deepening of the economic reform carried out in China, reduction in the number of employees in the national-owned factories will become unavoidable, and per employee industrial water use will change because of this. Obviously, there are shortcomings in using the measure of raw material consumed to describe an aggregate situation that includes different kinds of industries. Production in terms of number or weight of products can just be used in a less aggregate situation. Only the same or comparable products can be put together by weight, length, or pieces. In a certain disaggregated level analysis, at a factory level for example, the measures of total production in products, and raw materials consumed may be better indicators than the gross productive value and the number of employees for reasons discussed above.

A dominant factor influencing the choice of parameter in projecting industrial water demand is the availability of data. In the available Chinese long-term projections of industrial growth, the targets are rarely expressed in terms of material production, except for a few major products, but often in terms of value production. However for most urban areas, disaggregated levels of historical water use data, such as data on water use in different kind of industries, are rarely available. They greatly restrict the use of measures that require more disaggregated data so that there are few example in the literature using the indicators of material production in a long-term or large scale industrial water use analysis and forecast.

Limited by data availability, only two proxies of the scale of industry: value production and number of employees, are analysed in the following to see how close their relation is to the industrial water use. Data representing two levels of scale, inter-city scale and city scale, are used in the analyses.

5.2.1 Value Production and Industrial Water Use

5.2.1.1 Inter-city level analysis

From the Chinese Statistical Year-books, data on industrial water use in thirty-one cities from 1985 to 1991 are available; and from the Chinese Cities Statistical Year-books, the value of industrial production of these cities from 1985 to 1988 was obtained. The industrial water use and the value production of the thirty-one cities from 1985 to 1988 were analysed by using the simple regression method. The regression equation obtained is:

$$Q_i = \underset{(1988.15)}{2488.69} + \underset{(0.00117)}{0.01726}V_i \qquad (5.1)$$

Q_i is the industrial water required in ten-thousand cubic metres; V_i is the industrial productive value in ten-thousand yuan; the numbers in brackets are the standard errors of the estimated intercept and slope.

The correlation coefficient r is 0.810, and R squared is 0.656, with 2-tailed significance at less than the 1% level (see Figure 5.1).

The same correlation analysis was undertaken separately by years. The results were presented in Table 5-1.

Table 5-1. Results of Regression Analysis Between Value Production and Industrial Water Use in Separate Years

Years	r	R squared	Slope	S.E. of Slope
1985	0.921	0.848	0.01008	(0.00082)
1986	0.904	0.817	0.01746	(0.00159)
1987	0.869	0.754	0.01846	(0.00202)
1988	0.784	0.614	0.02151	(0.00328)

Some features are revealed by the above results. Firstly, the correlation coefficients decreased while the slopes increased from 1985 to 1988 (Table 5-1). This may be explained by the fact that the industrial water use per unit of industrial productive value increased during this period with varying rates of increase among the cities. However according to a joint report of the National Construction Ministry and the Planning Committee (1990), the national average per unit value industrial water use decreased dramatically from 1984 to 1990. This contradiction may be caused by several reasons, such as:

(a) the dramatic increase of industrial water use in several large cities such as Shanghai and Guangzhou, which may be caused by a few newly-built high water-consuming firms. This may have greatly influenced the regression line.

(b) the productive value used in analysis is incomplete. It is suspected that the productive value created by private-owned and foreign-invested industries was excluded, but water used by them was included.

Secondly, from the distribution of the points (cities) in the figure (Figure 5.1), the more northern cities deviate below the regression line, while the more southern cities are above it. This is clearer in Table 5-2, where the residuals between the observed and the estimated are listed from negative to positive. This is perhaps the regional climatic or hydrological effect on the industrial water use. From the lack of order in the middle rows of the table, it is revealed that there must be other factors affecting the unit use rate of industrial water, such as urban industrial structure.

Table 5-2 Comparison Between the Observed and Estimated Industrial Water Use of 1987 in Chinese Cities (10^4 cubic metres)

Cities	Location	P.V.*	Observed	Estimated	Residual
Beijing	NC	3,277,303	25,121	59,055	-33,934
Tianjin	NC	3,082,062	29,325	55,685	-26,360
ChangChun	NE	744,954	4,680	15,347	-10,667
Shenyang	NE	1,796,674	25,808	33,499	-7,691
Harbin	NE	971,634	12,399	19,259	-6,860
Kunming	SW	521,746	4,866	11,494	-6,628
Guiyang	SW	344,593	2,568	8,436	-5,868
Urumuqi	NW	291,260	2,282	7,516	-5,234
Changsha	SC	421,435	6,283	9,763	-3,480
Lhasa	SW	5,538	15	2,498	-2,483
Yinchuan	NW	88,499	2,225	4,016	-1,791
Huhhot	NC	178,077	4,010	5,562	-1,552
Hefei	SC	391,903	8,417	9,253	-834
Fuzhou	SE	438,613	10,165	10,836	-671
Xian	NW	835,115	16,343	16,903	-560
Wuhan	SC	1,658,869	31,013	31,121	-108
Nanning	SE	224,468	6,878	6,363	+515
Jinan	NC	777,190	16,708	15,930	+805
Taiyuan	NC	682,825	16,991	14,274	+2,717
Zhengzhou	NC	480,855	14,149	10,788	+3,361
Xining	NW	135,588	8,222	4,829	+3,393
Chengdu	SW	837,701	20,400	16,947	+3,453
Hangzhou	SC	944,517	23,287	18,791	+4,496
Shijiazhuang	NC	682,825	22,702	14,186	+8,516
Lanzhou	NW	620,038	26,734	13,191	+13,543
Nanchang	SC	405,843	33,044	9,494	+23,550
Nanjing	SC	1,289,412	51,001	24,744	+26,257
Shanghai	SC	6,849,690	150,864	120,714	+30,150
Guangzhou	SE	1,752,604	68,794	32,739	+36,055

Note: P.V. means productive value in ten thousand yuan.

5.2.1.2 A city scale analysis

This analysis is based on time-series data for a city from 1955 to 1977, cited from an article by Ren and Jiang (1984). The relationship between industrial water use and value production was analysed by using a simple linear regression method. The following equation was obtained:

$$\underset{}{Q_i} = \underset{(2305.22)}{5644.63} + \underset{(0.00351)}{0.04215}V_i \qquad (5.2)$$

The meaning of the variables in the equation are the same as that in Equation 5.1 and measured in the same units. The correlation coefficient r is 0.934; and R squared is 0.873 (see Figure 5.2). It shows a better relationship between the two variables at a city level in this case. Another study based on one Chinese city was carried out by Wang and Mu (1991). The correlation coefficient r between urban industrial water use and industrial productive value was reported to be 0.987.

5.2.2 Number of Employees and Industrial Water Use

5.2.2.1 Inter-city scale analysis

From the Chinese Cities Statistical Year-books, the number of industrial employees in thirty-one large cities in the years 1986, 87, 89, and 90 were quoted. Combined with the industrial water use data obtained from the Chinese Statistical Year-books of the same cities in the same years, the association between the number of employees and industrial water use was analysed by using the simple linear regression method. The equation obtained was:

$$\underset{}{Q_i} = \underset{(3075.36)}{-3403.48} + \underset{(36.045)}{421.70}E_i \tag{5.3}$$

in which, Q_i is the quantity of industrial water use in ten-thousand cubic metres; E_i is the number of employees in ten-thousand people.

The correlation coefficient r is 0.72996, and R squared is 0.53285, with two-tailed significance at less than 1% level (see Figure 5.3). The reasons for the lower value of R squared obtained from the employee analysis than that was obtained from the industrial value analysis will be discussed later.

5.2.2.2 A city scale analysis

From the Gansu Provincial Statistical Year-books, the number of industrial employees of Lanzhou city in the years 1982-87, 89, and 91 were obtained. The

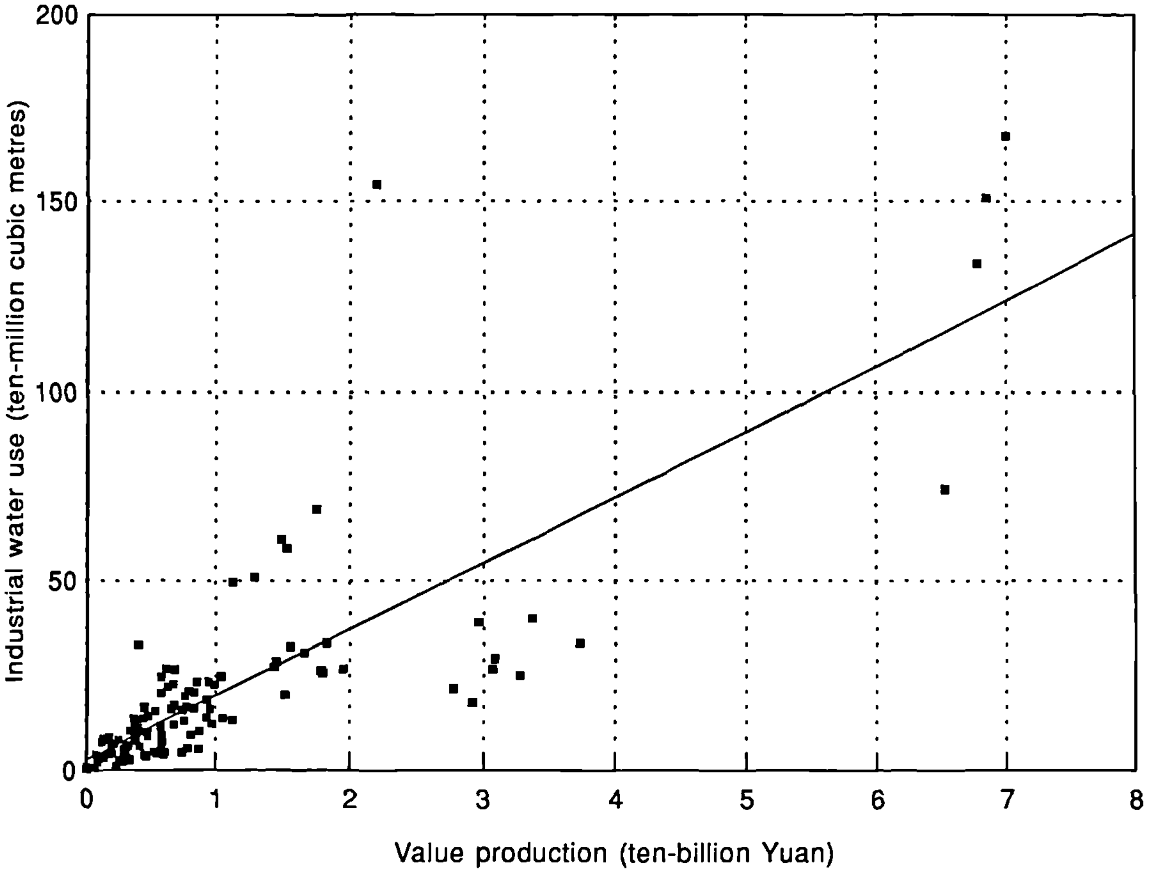


Figure 5.1 Industrial water use and value production (Inter-city)

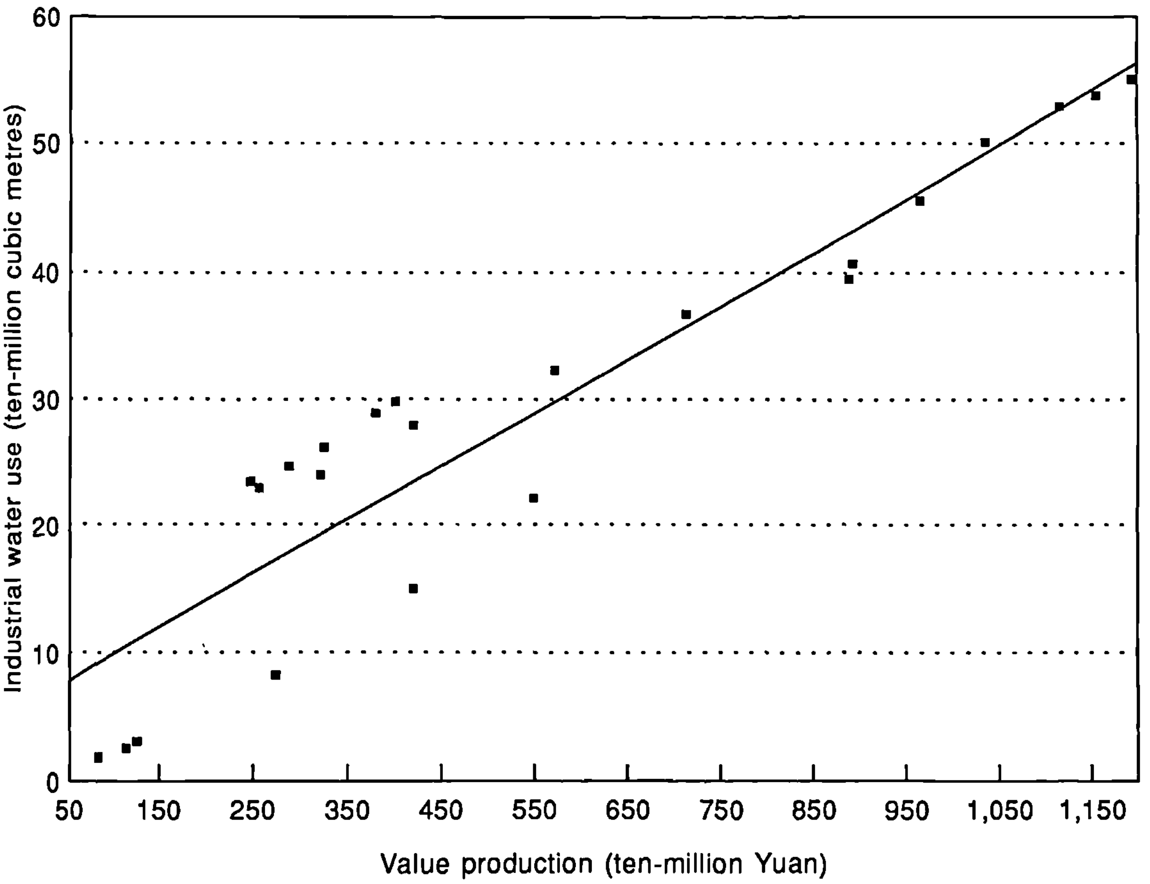


Figure 5.2 Industrial water use and value production (city scale)

industrial water use of the city in these years was available from both the Water Company's statistics in the city and the Chinese Statistical Year-books. The eight pairs of data (see Table 5-3) were analysed by using the same linear regression method. The equation result is:

$$Q_i = -2633.60 + 757.90E_i \quad (5.4)$$
$$(11588.77) \quad (333.50)$$

in which, the meaning of the variables are the same as that in Equation 5.3, and measured by the same units.

Table 5-3 Industrial Water Use and Number of Employees in Lanzhou

Year	Industrial Water Use (in 10^4 m^3)	Number of Industrial Employees (Persons)
1982	19304.96	336100
1983	18403.30	325100
1984	19753.34	343900
1985	20309.00	306696
1986	24576.00	313000
1987	26730.00	319846
1989	29277.00	390553
1991	29939.00	427130

Source: LWC, 1982a-87a, 89a, 91a; Gansu Provincial Statistical Bureau, 1982-87, 89; and the State Statistical Bureau of China, 1991a.

In this case, the correlation coefficient r is 0.6802, and R squared is 0.4627, while the two variables are correlated to each other at the significant level of 93.7% (see Figure 5.4).

5.2.3 Discussion and Conclusion

From the above analyses, it can be seen that the scale of industry, whether in terms of value production or number of industrial employees, is a significant factor affecting industrial water use. By comparing the associated coefficients obtained, it may be suggested that value production is a better explanatory

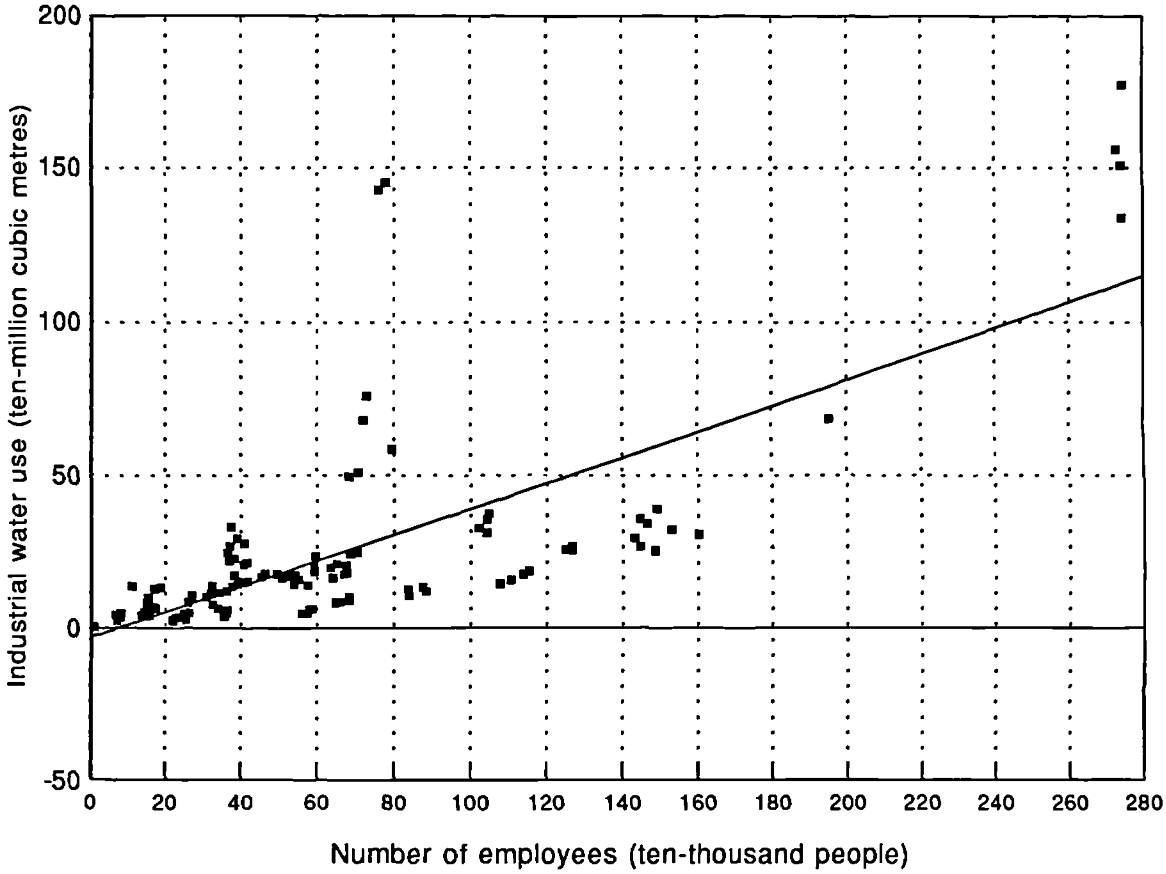


Figure 5.3 Industrial water use and number of employees (Inter-city)

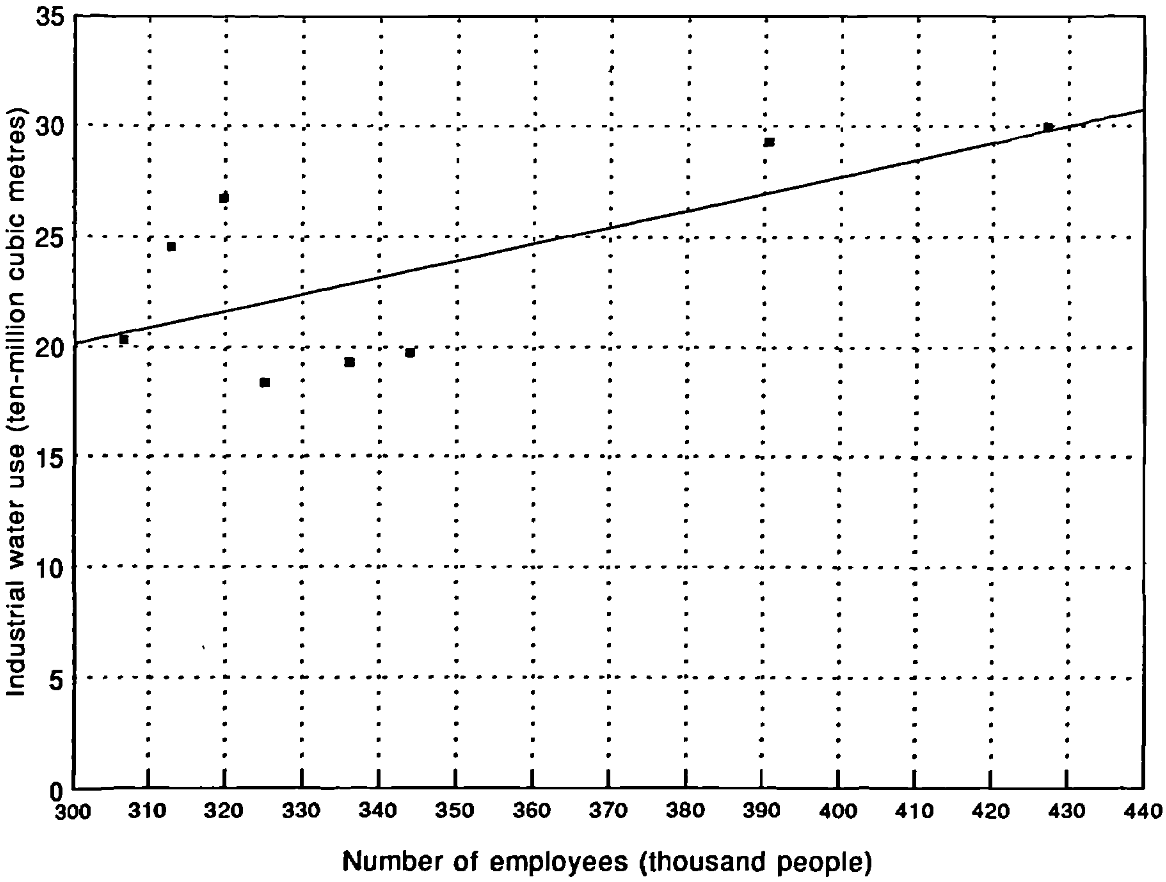


Figure 5.4 Industrial water use and number of employees (Lanzhou city)

variable than the number of employees in terms of the Chinese aggregate urban industrial water use.

The reasons for the poorer relationship between industrial water use and number of employees than that between industrial water use and value production are not very clear. For the inter-city scale analyses, a major reason contributing to this is, perhaps, the variation of industrial labour productivity among Chinese cities. Since the uneven-developed urban industries, including structure of industries, management levels, skill of workers, and technologies employed, the industrial labour productivity varies enormously from the South-coastal cities to the hinterland cities of China. This might also be related to the overmanning situation that varies among cities. The data used in the city-scale analyses, in terms of productive value and number of employees, did not come from the same source nor for the same city, so that no explanation can be made for the results obtained.

Whether in an inter-city cross-sectional analysis, or in the time series analysis of a single city, there was not found to be much difference in the strength of the correlation between industrial water use and value production or number of industrial employees. This is a different result from that obtained from the analyses of residential water use, in which the R squared decreases with disaggregation. This was mainly explained by the obscurity of some variables which occurred during the aggregate process.

For industrial water use, it may be argued that there is less stochastic or random variation than that in residential water use. Although stochastic factors exist in the industrial sector, such as individual behaviour in the operating process, climatic change, etc, their effects are comparatively less significant compared with their effects in the residential sector. Given a certain productive process, water needed for it may be treated as almost fixed without considering the improvement in technology. Another element contributing to this is perhaps the fact that the number of industries is much less than the number of population, which enables the analysis to be more disaggregated. The less random variation of industrial water use may be the major reason for explaining the similarity in results in terms of the coefficient strength obtained from inter-city scale and a city scale analyses.

5.3 THE STRUCTURE OF INDUSTRY

The structure of industry in a city or region is defined as the proportional composition of different types of industries in terms of value of products, number of employees, or other relevant parameters to indicate the scale of industry. For example, the structure of industry in a city can be demonstrated by a Pie-chart with each group of industry occupying a piece of it according to value production. The structure of industry is an important factor affecting industrial water use, because unit water use varies enormously from one type of industry to another.

Table 5-4 gives an example of water intake per unit value of products in different categories of industries in Beijing. It shows that coal, primary metal, chemical, and building material industry need more water than other industries in the city for manufacturing the same value of products.

Another comparison is among the unit use per employee by industrial groups. Table 5-5 is quoted to demonstrate the great variation of water use per employee among different industry groups. Major industries reporting high rates of water use per employee include those producing petroleum and coal products, lumber and wood products, food and food-related products, and chemicals and related products.

Table 5-4 Water Use Rate and Recycling Rate by Industrial Group in Beijing in 1980

Industry Group	Unit Use Rate ($m^3/10^4$ Yuan)	Recycling Rate (%)
Petroleum products	138	92.0
Coal products	1,163	10.0
Primary metal products	595	75.7
Chemical and allied products	591	76.4
Machinery	234	24.3
Building material	594	0.8
Lumber and wood products	114	24.5
Textile products	264	20.6
Grain and oil processing	83	1.3
Food products	388	8.0

Source: Yang, Ren, et al., 1984.

Table 5-5 Unit Use Per Employee by Industrial Group

SIC Code	Industry Group	Unit Use/Work Day (gallons)
20	Food and kindred products	2,026
21	Tobacco manufacturers	100
22	Textile mill products	43
23	Apparel and other textile products	38
24	Lumber and wood products	2,253
25	Furniture and fixtures	104
26	Paper and allied products	3,454
27	Printing and publishing	81
28	Chemicals and allied products	1,443
29	Petroleum and coal products	9,392
30	Rubber and plastic products	290
31	Leather and leather products	169
32	Stone, clay, glass, and concrete products	1,146
33	Primary metal industries	772
34	Fabricated metal products	315
35	Machinery, except electrical	158
36	Electrical and electronic equipment	162
37	Transportation equipment	173
38	Instruments and related products	213
39	Miscellaneous manufacturing industries	61

Source: California Department of Water Resources (1982), p76-80; cited from Prasifka, 1988, p38.

In terms of the per unit product in weight, piece, or length, the water use per unit rate for different products is more varied. Table 5-6 documents the water use quota for some industrial products issued by the Chinese government in 1984. The great variation in use is obvious from it.

Table 5-6 Water Use Quota for Producing Some Products

Products	Unit	Water Intake	Recycling Rate (%)
Ordinary steel	m^3/ton	10-72	80-95
Raw coal	m^3/ton	1-2	
Raw oil	m^3/ton	9.9-14.3	
Synthetic ammonia	m^3/ton	3.5-30	93.5-99.5
Polyamide fibre	m^3/ton	680-2,100	
Paper	m^3/ton	80-165	
Beer	m^3/ton	70-80	
Electricity	m^3/kkwh	4.9-12.8	95.0-97.5
Cement	m^3/ton	0.91-3.84	54.8-77.6
Gentamicin	m^3/ton	144,000-300,000	
Vitamin C	m^3/ton	3,600-9,000	

Source: The Ministry of Urban and Country Construction and Environment Conservation, and the State Economic Committee, 1984.

In general, as mentioned by Jones, Boland, et al. (1984), the water-intensive industries are: thermoelectric power generation, chemical industry, primary metal industry, paper industry, petroleum and coal industries. For the country as a whole, the above industries usually take a dominant part of the industrial water use. For a city, perhaps one group of such industries may consume up to 80% or more of the total industrial water intake. In Table 5-2, the very high positive residuals obtained in northern city Lanzhou, Shijiazhuang, and Taiyuan may be due to their industrial structure in which chemical, petroleum, or coal industries play dominant role in these cities.

The structure of industry is often quite different from one city to another, and the structure of industry in a city can change over time. Therefore, when forecasting long-term industrial water demand, it is better to take the industrial structure into account, especially under the following situations. Firstly, in forecasting water demand for a city with an obvious dominant industry; secondly, where a thermoelectric power station is located in the urban area; and thirdly, when the forecast of water demand is for a small or mid-sized city where the existing industrial scale is limited, but rapid development is likely to occur or is planned.

In fact, the structure of industry is a problem of disaggregation if it is considered in water demand forecasting. As discussed in Chapter Two, the greater the disaggregation, the more data are needed; not only data from historical records, but also the projected or estimated values as well. Hence, it is not a simple task to estimate the future industrial structure and combine it into the process of water forecasting. That is why it is often assumed by forecasters that the industrial structure of an area will remain constant, as in Wang and Mu (1991). However, if it is possible to foresee that the industrial structure will be quite different from the present pattern, which may be available from urban development plans or other sources, it should be considered in the process of water demand forecasting.

5.4 RECYCLING OF INDUSTRIAL WATER

Industrial water recycling is the direct reuse of water, without treatment or with limited treatment, at the same general location or for the same purposes (Prasifka, 1988). The recycling rate is the percentage of water reused divided by the gross water needed, which can be calculated by the following formula:

$$\eta = \frac{Q_t - Q_c}{Q_t} * 100\% = (1 - \frac{Q_c}{Q_t}) * 100\% \quad (5.5)$$

in which, η is the recycling rate; Q_t is the total water demand; Q_c is the fresh water added to compensate the losses in the process, or to maintain the required water quality.

Recycling rate of industrial water use can be raised by the firm itself when the benefit from recycling is higher than the cost of installing recirculation facilities, or forced by regulatory policies that restrict water use or control environmental pollution. In China, the latter is a more powerful factor accounting for the increase in the recycling rate. As mentioned in Chapter Three, the recycling rate of industrial water use in each Chinese city is required by governmental regulation to be over 40%; otherwise, any increase in industrial water supply capacity will not be permitted. From 1984 to 1990, the Chinese national average recycling rate of industrial water use was reported to have increased from less than 20% to around 45% since the implementation of this policy (The Chinese Ministry of Urban and Country Construction and Environment Conservation, and the State Planning Committee, 1990).

Different types of industry are subject to different limitations in increasing water recycling. When Q_c, or the quantity of compensated water, is very low compared with Q_t, the recycling rate may reach a very high level. For example, so little water used for cooling in the thermoelectrical power generation is lost during the productive process that the recycling rate can be as high as 98%. However industries that use water mainly for processing purposes cannot increase their recycling rate to a very high level, because water that is incorporated into the products, evaporated into the air, or discharged with the wastes, cannot be recirculated any more. Table 5-4 demonstrates the variation in water recycling rates among categories of industry in 1980 in Beijing. Optimal recycling rate for several industrial groups are given in Table 5-7. In general, industries that probably have high recycling rates are those that need large quantities of water mainly for cooling purpose, such as thermoelectric industry, primary metal industry, chemical industry, petroleum and coal industry, etc. Recycling rates also change with the size of firms. Large firms usually can raise the recycling rate higher than that possible in small firms.

The effect of water saving is obvious by increasing the recycling rate. If the total water demand Q_t is fixed, the fresh water that needs to be added Q_c will become less when the recycling rate η is increased. In China, the per ten-thousand yuan industrial water use was reported to have decreased from 459 cubic metres to 270 cubic metres with the improvement of the recycling rate from 20% to 45% (The Ministry of Urban and Country Construction and Environment Conservation, 1990). The increase in the recycling rate of industrial water has been identified as the most important strategy to ease water shortages in many Chinese cities.

Table 5-7 Optimal Recycling Rate for Industrial Groups

Industrial Group	Optimal Recycling Rate (%)
Iron and steel industry	90-95
Nonferrous metal industry	80-90
Petrochemical industry	85-95
Ordinary chemical industry	80-90
Paper industry	50-60
Food industry	30-50
Machinery manufacturing industry	50-60
Textile industry	50-60
Printing and dyeing industry	30-50

Source: Yang, Ren, et al., 1984, p96.

5.5 OTHER FACTORS AND INDUSTRIAL WATER USE

From a long-term perspective, industrial water use may also be influenced by changes of industrial water price, new regulatory policies related to water use and discharge, technological improvements, and so on. Restricted by data availability, it is impossible to analyse these factors by using a more detailed method, except for a general assessment.

5.5.1 Water Price for Industrial Use

Theoretically, like any other commodity, the price of water should be a very important factor affecting industrial water demand. The higher the price, the less is the industrial water demand. However, because expenditure on water is only a very small part of the total cost of industrial production, and because many industrial firms in China draw water directly from ground or surface water sources by themselves rather than buying from water supply companies, it is argued that water price cannot play a significant role in reducing industrial water use.

For various reasons, to date there are fewer assessments of the influence of price on industrial water use than of its influence on residential water use in the literature. De Rooy (1974) found that firms do adjust quantities demanded in response to even small price changes. The result revealed by Rees, who took industries in South East England as a whole, was that price of water was significant, at the 0.95 level of probability, but the degree of explanation (R squared) achieved was low (Rees, 1969, p54). Water price has been combined into industrial water demand models, but it was treated as a factor to adjust the forecast result by the price elasticity, rather than as an explanatory variable combined into statistical models explicitly (Davis, et al., 1988; Xu, 1992a). Economic theory requires the use of marginal, not average price. If average prices or cost are used instead of marginal prices, the model will be mis-specified and the estimates will be biased (Kindler, et al., 1984, p59).

In China, water price has been used as a tool to control industrial water use. As mentioned in Chapter Three, there is a government issued standard water use quota for every industrial product, and even details for different stages of productive process for some products. It is referred to by local WEOs (Water Economization Offices), according to the local situation, for the formulation of local increasing punitive water rate structure, and some other rules about optimisation of water use. When water intake by an industrial facility for producing a product is over the standard quota adjusted by the local authority, higher water rates, which are several times up to fifty times higher than the normal water rates, will be charged. In this case, the price of water has the characteristic of a control with administrative pressure, not merely economic control. Its purpose is to cut the amount of water that is above the standard quota, rather than to influence the whole water use.

The water demand quota itself is questionable since there is flexibility in the adjustment made by the local water economization authorities. In cities where a water shortage has not occurred, the water use quota for a product may be much higher than the national standard by giving some excuses, such as low level technology adopted.

For the simple reason that data is unavailable, it is not possible to analyse the effect of the increasing rate structure of the price of water in China. However, one effect of it is obvious and can be proved by past experience. It is to help cut the part of industrial water use above the standard quota, as what it is intended to do, although the part above the quota is somewhat ambiguous due to the criteria (quota) is not rigid. In this sense, the function of an increasing rate structure of water price currently operating in the Chinese urban water management greatly depends on the policies or regulations for water use.

5.5.2 Water Use Optimisation Policies

Policies in China are powerful in terms of how they can affect people's behaviour through various effective measures. When water resources become scarce, policies towards the rational allocation of water among a variety of users will be necessary. First of all, an ad hoc strategy usually encourages an economization of water uses. As stated before, in today's Chinese urban areas, the problem of water shortage has brought in the corresponding water use optimisation policies. The effect of these policies on water demand is crucial by the way of administrative, economic, and technological control. This has been proven by the achievements of the Chinese water economization movement which started since 1984. This was discussed in Chapter Three.

Water use optimisation policies influence industrial water demand comprehensively. The change in water price, technological improvements, and raising of the recycling rate may be all related to one water optimisation policy. Therefore, it can be argued that a policy defines an invisible frame for some factors that they can only change within it. It may be difficult to estimate the effect of a water optimisation policy, but the environment defined by the policy helps to estimate the possible changes of some related variables.

5.5.3 Industrial Technological Improvements

During the process of industrial development, technological improvement occurs continuously. The change of technology adopted in the productive process may cause a change in the quantity of water needed (De Rooy, 1974). Particularly, when water becomes a restrictive factor in industrial production, technological improvement will tend to reduce water use, as has happened from the restriction of energy and some metal materials in history.

Past experience has shown that little effort towards reducing water intake was made in the industrial technological improvements. This is probably because water had not seriously restricted industrial production in the past. However, today, water shortage has become a nation-wide problem in China. Water saving technologies are much encouraged and required by government policies. Under this situation, it is very likely that technological improvements will result in a reduction in industrial water use.

The effect of technological improvements in a long-term industrial water demand forecasting should not be ignored. However, there is still a problem about how to estimate the effects and combine them into long-term forecasting. Past experience of technological improvements may not be a good guide for the future.

Other factors may directly or indirectly affect industrial water demand, such as climate, size of industrial facility, quality of raw material, and so on. Some industries, textiles for example, require a comparatively higher standard of air humidity. These industries, generally located in arid areas, need more water for air conditioning than those in humid areas. Big firms usually have a higher recycling rate and a lower per unit water use than small ones. The quality of raw materials, such as in the food industry for instance, directly affects the quantity of water needed to clean them. Phenomena like these may show some relationships between industrial water use and some other factors.

Factors affecting industrial water use should also be distinguished into macro and micro factors, like the distinction made in the residential water use sector. Factors which need to be considered in an analysis greatly depend on the scale concerned. In this analysis, it was deliberately decided to concentrate on long-term city-wide Chinese urban industrial water use forecasting. It generally treats all the industries in any chosen city as a whole, except where the structure of industry is concerned. Therefore, some micro factors are omitted in the analysis, or they are treated as random variables. This is the implicit principle for the choice of the factors in the analysis.

5.6 SUMMARY

In this chapter, major factors affecting industrial water demand are analysed in connection with the Chinese situation. It was found that gross productive value is a good measure for the industrial scale and a better explanatory variable of industrial water use. Industrial structure can also be taken into account in the process of forecasting by way of disaggregation, when necessary and when data are available. The recycling rate is given priority by the Chinese water economization authorities so that it is also essential to combine this into a water use forecasting model. There is not enough evidence to estimate the effect of water price in the Chinese urban water management mainly due to the current imperfect market economy. Water optimisation policies are often associated with target measures with respect to recycling rate, technological improvements towards reducing water use, etc, and hence their effects on water use cannot be analysed separately. The effect of technological improvements can only be estimated in a general way. These are the factors that are statistically or qualitatively analysed in the industrial water use sector. They are based on the principle that the analysis provides a good basis for building-up of a long-term urban industrial water demand forecasting model.

Chapter Six
AGRICULTURAL WATER USE

6.1 INTRODUCTION

City is an administrative concept in China. It is always composed of an urban centre and a certain rural area surrounding it. The normal administrative arrangement is that several rural counties are under the jurisdiction of a city council. The larger a city is, the more rural counties it contains (Kirkby, 1985, p60-72). The jurisdiction of Lanzhou, for example, currently covers three rural counties as well as five urban districts. When using statistical data in terms of a city, attention must be paid to the fact that information for both the urban and rural areas is always mixed together, except for when a distinction is clearly made. Even in the districts, which are the administrative unit in the Chinese urban areas, farming activity is often involved, especially in the outer districts of cities, and small and mid-size cities.

By using official statistics, the boundary drawn for urban water demand forecasting must coincide with the administrative divisions, because of the availability of data. The data available from the local or national statistics in China is all based on administrative divisions. Therefore, in terms of urban water demand in China, agricultural water use has to be taken into account.

Agricultural water use among Chinese urban areas varies enormously because of the different levels of urbanization from city to city. In less urbanized cities and districts, for example, those many small cities which were converted from counties in recent years, agricultural water use takes a considerable portion of total urban water requirement; in more urbanized cities or districts, agricultural water use takes a small part, or even negligible sometimes. The trend, according to past experiences, is that a city's agricultural water use, especially in terms of portion, tends to decline with the process of urbanization.

Urban agriculture often has its own water supply sources and facilities, which are independent of the urban public water supply companies. However under some situations, agricultural water is drawn from the same water source, or even from the same facilities as those used for other purposes. Baiyin city, for example, channels water from the Yellow River, which is about 30 km from the city, for all purposes of its urban water uses, including irrigation, because it is located in an arid area and is short of any kind of water resources at the locality.

Agricultural water use itself is a very complicated issue. It is composed of the water used for farming, forestry, animal husbandry, fishery, and daily life of the farmers. However, the dominant part of agricultural water use is the water used for farmland irrigation, which usually takes over 95% of the urban agricultural water uses in China. Therefore, for convenience and simplicity, only irrigation water use is discussed in this chapter; and even when the concept of agricultural water use is mentioned later, it refers to the water used for irrigation only.

Many factors affect water demand for irrigation. These include the irrigated area, climate, combination or structure of crops, method of irrigation, efficiency of canal and ditches, the situation of landscape, soil condition, availability of water, etc. The irrigated area is treated as the factor affecting the demand for agricultural water use; the others are treated as affecting the intensity of agricultural water use, or the agricultural water use per unit area. The function of the major factors will be discussed in the following sections.

A major problem for the analysis of agricultural water use is that there is very little data available, since neither national nor local statistics take agricultural water use into account. Hence only limited quantitative analysis was undertaken.

6.2 IRRIGATED AREA AND AGRICULTURAL WATER DEMAND

In general, it may be said that the larger the irrigated area, the greater the water demand; or in other words, agricultural water use increases with the expansion of area needed to be irrigated. A regression analysis between irrigated area and water used is presented below to test this hypothesis.

From the "Utilization of Water Resources of Continental Rivers" (Lanzhou Water Resources Survey & Engineering Institute, 1986), data on water supplied and area actually irrigated in 1980 of sixty-one irrigated areas were obtained, including water drawn from various sized reservoirs, diversion projects, pumping stations, and other kind of sources. The relationship between water supplied and area irrigated was analysed by using a simple regression method. The equation obtained is:

$$Q_a = \underset{(45.2369)}{-73.4783} + \underset{(0.0446)}{1.1825A_i} \qquad (6.1)$$

Q_a is the water supplied in million cubic metres; A_i is the area actually irrigated in thousand mu (one mu equals to one fifteenth of a hectare).

The correlation coefficient r is 0.961, and R squared is 0.923, with two-tailed significance at less than 1% level (see Figure 6.1). So a good relationship between the two variables is shown by the above result.

Although the data used was not chosen from different urban areas but rural areas, they may represent some common relationships between area irrigated and water used, because agricultural water demand, whether in rural or urban areas, should follow the same principle of meeting the needs of water by crops.

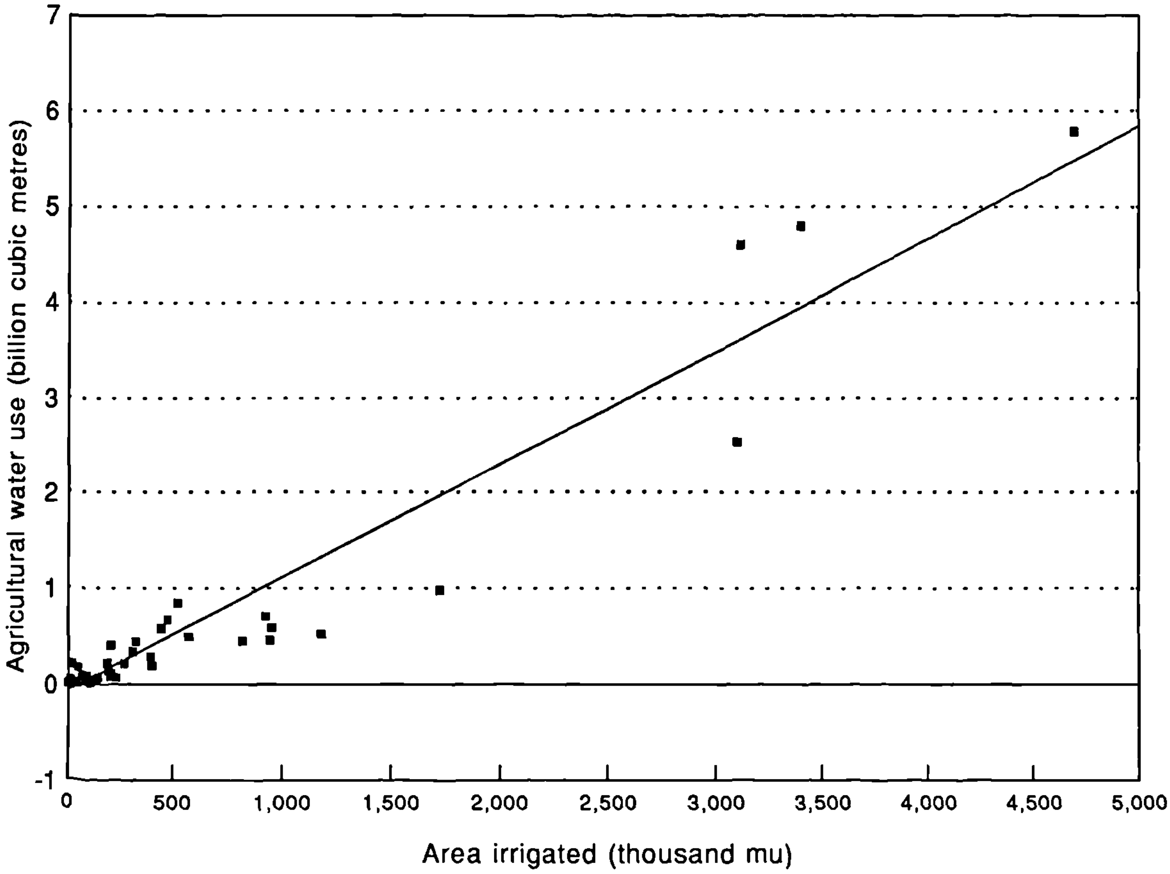


Figure 6.1 Agricultural water use and irrigated area

Of course, there are some differences between urban and rural agriculture, which may affect the agricultural water demand. For example, vegetable planting often plays a dominant role in Chinese urban agriculture, but in rural areas grain crops are more dominant; and irrigation facilities in urban agriculture are much better than those in rural areas. However, all these differences can be taken into account by introducing some factors affecting the intensity of agricultural water use that will be discussed later.

Some other variables could also be adopted as the factor affecting the demand for agricultural water use, or to indicate the scale of agriculture, like grain production, or food requirements, which were the basic variables considered in the linear programming models (Gisser, 1970). However, the unavailability of data restricts the analysis of the function of these factors, so that no comparison can be undertaken with the function of area irrigated. In terms of the literature of Chinese agricultural water use study, area irrigated is the factor commonly adopted.

6.3 CLIMATE AND PER UNIT AREA WATER USE

Theoretically, irrigation is to make up the difference between efficient precipitation and total water needed by crops for normal growth. When rainfall is plenty, irrigation water needed by crops will be reduced or may even become unnecessary. When the weather is dry and temperature high, the evapotranspiration is huge, and the same precipitation or irrigation may last fewer days for the crops to grow normally compared with crops in cooler and more humid weather conditions. Therefore, water demand for irrigation is influenced by climatic conditions.

The efficiency of precipitation with respect to agriculture is defined as that part of rainfall that penetrate the soil and can be directly used by crops. It is calculated by the following simple formula:

$$P' = n * P \tag{6.2}$$

in which, P' is the efficient precipitation; P is the total precipitation; and n is the coefficient.

The value of n depends on the precipitation at each period of rainfall, the strength of it, temperature, crops, and growing periods of crops, which can only be obtained from field experiments. Table 6-1 gives an example that the value of 'n' varies with precipitation in the Hilongjiang Province of China.

Climate changes from place to place, and precipitation varies stochastically from one year to the next. The former causes the spatial variances in per unit area water demand and total irrigating water needed by crops; the latter causes the annual variances in water requirement during the whole life period of crops. Table 6-2 gives the per unit area total water needed by some major grain crops during their life time in different regions of China and in different types of hydrological years.(2)

The irrigation water demand is the total water needed by a crop, including the losses of necessary field seepage and evaporation, minus the efficient precipitation during its life time. Table 6-3 gives an example of irrigation water demand for winter wheat in five northern Chinese provinces and in different

(2) According to hydrological frequency, three categories of hydrological years is classified based on the annual precipitation. When the precipitation of a year is equal to or less than that at 75% frequency, it is called a dry year; when the precipitation of a year is equal to or higher than that at 25% frequency, it is called a humid year; when the precipitation of a year is between the values from 75% frequency to 25% frequency, it is called a mid-dry, or mid-humid, year.

types of hydrological year. It shows that rainfall can make up about 20% to 50% of the total water demand for winter wheat in different hydrological years in these areas.

Table 6-1 The Coefficient of Efficient Precipitation (n) in Hilongjiang Province (China)

Precipitation (mm)	n (100%)
<5.0	0
<50	1.0
50-100	0.8
100-150	0.75
150-200	0.70

Source: Yang, Ren, et. al., 1984, p75.

Table 6-2 Spatial Variance in Total Water Demand for the Major Chinese Crops (in cubic metres per mu)

Crops	Regions	Dry-year	Mid-year	Humid-year
Rice	Northeast China	250-500	220-500	200-450
	Yellow River Valley & North China Coast Area	400-600	350-550	250-500
	Yangtse River Valley	400-500	300-500	250-450
	South China	300-400	250-350	200-300
Winter Wheat	North China	300-500	250-400	200-350
	Yellow River Valley	250-450	200-400	160-300
	Yangtse River Valley	250-450	200-350	150-280
	Northeast China	200-300	180-280	150-250
	Northwest China	250-350	200-300	-----
Cotton	Northwest China	350-500	300-450	-----
	North China & Yellow River Valley	400-600	350-500	300-450
	Yangtse River Valley	400-650	300-500	250-400
Corn	Northwest	250-300	200-250	-----
	North China & Yellow River Valley	200-250	150-200	130-180

Source: Yang, Ren, et al., 1984, p69.

Table 6-3 Annual and Spatial Variance in the Demand for Irrigation Water for Winter Wheat (in cubic metres per mu)

Province	Hydrological Frequency %	Efficient Rainfall	Total Water Demand	Irrigating Water	Times of Irrigation
	75	60	200-300	140-240	4-6
Shandong	50	80	200-300	120-220	3-5
	25	107	200-300	100-200	3-4
	75	67	250-300	183-283	5-6
Shanxi	50	100	250-300	150-200	4-5
	25	130	250-300	120-170	3-4
	75	37	200-300	163-263	5-6
Hebei	50	80	200-300	120-220	3-5
	25	93	200-300	107-207	3-4
	75	46	200-300	154-256	5-6
Henan	50	66	200-300	134-234	4-5
	25	120	200-300	80-180	3-4
	75	95	250-350	155-255	4-5
Shannxi	50	130	250-350	120-220	3-4
	25	160	250-350	90-190	2-3

Source: Yang, Ren, et al., 1984, p72.

Climatic change over time is an important factor for forecasting agricultural water demand. Most forecasts were based on the past or present water use patterns of the same area rather than referring to other areas. From Table 6-2 and Table 6-3, the obvious effect of different hydrological years can be found. The effect of spatial climatic change is useful to forecasting when the local agricultural water use data is absent, and hence the experience of other areas is required for reference. In practice, it is necessary to forecast the agricultural water requirement under different hydrological frequencies, particularly three typical hydrological years; or combine agricultural water demand forecasting with long-term weather forecasting if it is available.

6.4 CANAL EFFICIENCY AND METHODS OF IRRIGATION

Two concepts should be distinguished in analysing agricultural water demand. One is the gross irrigation water used (Q_g), and another is the net irrigation water used (Q_n). The former is the quantity of water supplied by or drawn from any kind of water sources, including reservoir, well, river, etc. The latter is the quantity of water which reaches the farmland or the place to be irrigated, i.e. the gross water minus the losses of water during the transferring process from the source to the destination, including seepage, evaporation, and so on. The effective rate (δ) is used to measure the efficiency of water transfer by canals, ditches, or some other methods, which is calculated by the following formula:

$$\delta = \frac{Q_n}{Q_g} * 100\% \tag{6.3}$$

If there are several levels of canal, such as trunk canal, branch canal, lateral canal, and field ditch, and water flows through all the four level canals, the effective rate of each level canal is defined as the quotient of the quantity of water flowing out divided by the quantity of water flowing in. If the effective rates of the four levels are represented separately by δ_t, δ_b, δ_l, and δ_f, then the comprehensive effective rate (δ) of the whole transferring process should be:

$$\delta = \delta_t * \delta_b * \delta_l * \delta_f \tag{6.4}$$

The effective rate is related to the length of canal, or ditches, quality of facilities, level of management, condition of soil, situation of hydrological geology, etc. In China, the current effective rate of canals and ditches is between 0.45 and 0.60. With the improvements of irrigation methods and water transfer techniques, the effective rate can be dramatically raised.

Today, some new methods of water transfer from water sources to farmland have been developed and are being used instead of the old methods (Li Feng, 1992; People's Daily, 24th August 1992). Soft-tubes made of water proof cloth, and underground cement tubes, for example, have been adopted in some agricultural areas, although they cost more than the traditional methods.

Government subsidies are allocated to farmers who adopt the new techniques in order to encourage the spread of the water saving methods. It was said that the effective rate of water transferred by soft-tube is about 0.95. Therefore, compared with the traditional methods, the effective rate is doubled by using the soft-tubes; or the amount of water actually used for irrigation is increased two times. The effective rate of underground cement tubes is almost as high as that of the soft-tubes and much more reliable.

The method of irrigation affects the agricultural water demand very much, including both the net and gross water demand. Looking through history, it can be seen that the development of irrigation methods has always been towards increasing the efficiency of water use. The traditional methods were developed from primary flood irrigation to border irrigation, and to furrow irrigation; the modern methods developed from spray irrigation to drip irrigation, and so on. According to a report by Li Xinrui (1992), up to 50 per cent of water can be saved by changing from flood and border irrigation to spray irrigation based on the experience obtained from the North China Plain. The clear effects of water saving by adopting modern irrigation methods, from experiments carried out in the North-west China, were also reported in People's Daily (4th and 24th August 1992). By using the modern irrigating methods, i.e. spray or drip irrigation, water loss in the process of transfer is very little so that the effective rate of "canals", which are normally metal tubes, can be very high, nearly 1.

Due to financial problems, many poor Chinese agricultural regions cannot afford to adopt modern irrigation methods at present. Therefore, some cheaper ways have been developed, such as the method of film-covered irrigation. This is to allow water to flow slowly over plastic films in the field and to let water permeate the soil only through holes in the films around each plant. It is said that the function of this method is similar to drip irrigation, and about 30 per cent of water can be saved at a cost of only 1 per cent of the investment for developing drip irrigation (Daily of Science and Technology, 31st August 1991).

Some other water saving irrigation methods have been developed in China. For example, the rice field irrigation method invented by Lui Yanhe (People's Daily, 12th June 1992) is based on the knowledge of rice physiological and ecological characteristics, which needs 300 m3/mu water less than normal, and increases harvest by 12.6%. Another example is the successive achievements made in Henan province (People's Daily, 16th Sept. 1991), made by effective management through rationally distributing water among different irrigation zones that were classified comprehensively according to the situations of water resources, irrigation facilities, and soil characteristics.

Water saving irrigation was one of the eight agricultural technologies recommended by the Chinese Agriculture Ministry in 1992. It was reported that over five-hundred-thousand technological officials were sent to help farmers to adopt the water saving irrigation methods in 1992 (People's Daily, 25th March 1992).

In conclusion, water saving agriculture is becoming more and more popular in China under the encouragement of the government. In Chinese urban areas, irrigation methods used are always more advanced than those adopted in the rural areas for reasons of water shortage and a higher economic level. When forecasting the Chinese urban agricultural water demand for a future date, the effects of these factors should be considered or taken into account.

6.5 CROP STRUCTURE AND PER UNIT AREA WATER USE

Different crops, and different species of a crop, need various quantities of water for normal growth during their life time. Generally speaking, plants which originate from humid and hot areas need more water than those which originate from dry and cool areas, for example, rice usually needs more water than wheat; and vegetables need more water than grain crops. However there are some exceptions, especially the improvements in crop breeding techniques and related techniques can change the characteristics of crops enormously. Table 6-4, shows the degree of variation of irrigation water required by vegetables recorded in a northern Chinese city.

Table 6-4 Irrigation Water Used by Vegetables Recorded in A Northern Chinese City

Species	Water Use Quota cubic metres/mu	Time Period of Irrigation
cucumber	550	Late May to Mid. August
celery	535	Late May to Mid. August
aubergine	290	Mid. May to Mid. August
Chinese leaves	270	Mid. July to Early Sept.
cabbage	240	Late April to Mid. June
tomato	195	Late May to Early August
pepper	190	Late May to Early August
pumpkin	185	Late May to Early July
spring onion	170	Late May to Early July
radish	170	Late July to Early Sept.
bean	160	Mid. May to Mid July

Source: Yang, Ren, et al., 1984, p71.

Although a lot of effort has been made by agricultural scientists, the optimum per unit area of irrigation water required, or the irrigation water use quota for a special crop, is not often exactly known because it depends on so many variables such as climate, irrigation method, transfer techniques, soil structure, landscape, and so on. In practice, the knowledge about per unit area water use of a crop is generally obtained from the past experience. Therefore, it is common to use a comprehensive irrigation quota (M_g) multiplied by the total irrigated area to calculate the irrigation water used rather than to sum all the irrigation water used by all kinds of crops that occupy varied areas of farmland. Theoretically, the comprehensive irrigation quota M_g should be calculated by the following formula:

$$M_g = \sum_{i=1}^{n} A_i * M_i \qquad (6.5)$$

A_i is the percentage of the ith kind crop in terms of area; M_i is the irrigation water use quota of the ith kind crop.

The comprehensive irrigation quota is obtained by dividing the total water use by the area irrigated without considering how large an area is occupied by each kind of crop or vegetable. Since the crop structure is not very changeable in a given area from a short-term perspective, it is not necessary to recalculate from year to year if the climatic factor has been taken into account. In the long-term, however, the structure of agriculture in a region will probably change. For instance, as mentioned before, vegetable planting often occupies a dominant area in urban agriculture. With the expansion of a city, the area of vegetable planting will be increased; and the crop structure will be gradually adjusted. Therefore, in long-term urban agricultural water demand forecasting, it is better to consider the change in the crop structure, if information is available. It is, in fact, a question of disaggregation, as the industrial structure discussed in Chapter Five.

6.6 THE IRRIGATION WATER CHARGE

The forms and rates of irrigation water charge vary with different projects and under different conditions in China. This must have some effects on irrigation water use. The traditional way of charging for irrigation water in China is based on the area irrigated. The irrigation water charge per ha in the rice growing Dujiangyan Scheme, for example, ranged from 37.5 to 75 kg of husked rice plus half a day of labour for annual repairs through 1940s to the beginning of 1980s, the rate varying for land of different quality (X. Guohua, 1987). Since 1980s, the government has been trying to introduce a new form of irrigation water charge that is based on the quantity of water used, instead of the traditional way, in order to encourage water saving.

Although a lot of effort in measuring irrigation water has been made over the country since 1980s, there are still difficulties in charging for water use based on water quantity in some areas. Some alternatives have been adopted, such as an electricity charge, diesel oil charge, etc, since these are related to the amount of water pumped. In a village located in the North China Plain, which this author investigated, for example, irrigation water is charged according to the kilowatt-hour (kwh) that is consumed for pumping the water from wells. The price operated in 1992 was 0.40 yuan per kwh. Each well serves a fixed area that covers farmland owned by several families. There is a certain order of which piece of land will follow which during the process of irrigation. A kwh meter is installed in each pumping station, to measure the electricity used. Before starting irrigation, the kwh meter is checked and a record taken by the electrician, and then the amount of electricity used by each farmer is recorded after each irrigation work on his land is completed. The system is almost totally self controlled and managed by farmers, and this author was told it works very well.

In this case, the more water is pumped, the more electricity is consumed, and the higher electricity fee is charged. This means, in fact, water itself is still totally free. Although the Chinese government has started to collect water tax from various self-supply water users in the rural areas, farmers still do not need to pay for it. According to a small scale investigation, most farmers think water is so valuable that they would like to pump as much water as they think they require for their crops.

In conclusion, the traditional way of irrigation water charges based on the area irrigated fails to encourage effective water use in irrigation. The alternative method based on the quantity of water used, amongst other options, may have the effect of restricting ineffective water use, like losses, or overpumping, which were often caused by careless management combined with poor facilities. If both the facilities and management are good, the function of increasing water price is questioned whether it will greatly reduce irrigation water demand without teaching farmers appropriate knowledge and improvements in irrigation methods.

6.7 MULTIPLE CROPPING

In terms of the annual agricultural water use, a factor that should also be mentioned is the index of multiple cropping, which is a measure of number of harvests within a year utilising the same piece of land. In many agricultural areas of China, there is more than one harvest during a year; for example, two harvests a year in Summer and in Autumn, is a very common combination. When the land is utilized more than once within a year, the annual irrigation water use per unit area should be the sum of water used by two or more kinds of crops harvested from the same land. Since there is fallow land for the crop rotation, and it is impossible to take records of the crop rotation for every piece of land, the multiple cropping index is used to measure or represent the general situation of land use in an area, which is available from the statistics. For example, the multiple cropping index in Gansu Province is ranged between 1.00 and 1.86 according to statistics based on irrigation schemes.

The higher the index, the more harvests from the land, and the more water is needed for irrigation during a year. When the total annual water use is analysed with the area irrigated, like the regression analysis in Section 6.2, the factor of multiple cropping has been included. When per unit area of irrigation water use is calculated, whether by summing up water use from each time of irrigation or dividing the total water use by the area irrigated, the correlation between per unit area water use and the multiple cropping index can be seen.

However, the multiple cropping index in a region usually does not change very much from year to year, because it is quite related to the climatic condition. Therefore, in forecasting agricultural water demand based on historical data, the multiple cropping index factor may be neglected, but attention to it should be paid in calculating the per unit area annual irrigation water use, especially by summing up water use from times of irrigation.

There are other factors that may influence agricultural water use, like landscape or levelling of the farmland, soil and geohydrological conditions, and so on. The influence of these factors on the per unit area of irrigation water use may be only important in terms of a specific local situation or viewpoint over a large spatial scale.

6.8 SUMMARY

In this Chapter, factors affecting agricultural water use are analysed in accordance with the Chinese situation. Area irrigated was treated as the factor affecting the demand for agricultural water use, while the other factors were treated as affecting the intensity, or per unit area water use. The regression analysis between area irrigated and agricultural water use resulted in a very high correlation coefficient, so that the area irrigated is a good predictor of agricultural water use. Factors such as climate, structure of crops, irrigation methods, and multiple cropping index may cause the dramatic fluctuations of per unit area irrigation water use. The efficiency of canals and ditches can be measured by the percentage of water reaching the irrigated land, so that this function is easily understood. It can be taken into account by adjusting the total water demand or per unit area water use.

Changing irrigation charges from that based on area irrigated to that based on the quantity of water used may reduce inefficient water use. However, it is uncertain whether or not this will reduce the net per unit area water use unless the methods of irrigation are improved.

From the above analyses, it can be seen that many of the factors affecting agricultural water use are closely bound to the physical environment, like climate, crop structure, multiple cropping index, soil condition, etc. The function of these factors is comparatively stable for a given area within the parameters set by stochastic fluctuation of variables such as climate. Other factors, like methods of irrigation and water transfer, irrigated area, the method and rate of irrigation charges, may cause changes in the demand for irrigation water. Therefore, in forecasting future agricultural water use, more attention should be paid to these changeable factors.

Chapter Seven
COMMERCIAL WATER USE

7.1 INTRODUCTION

Commercial water use comprises of the water used by trade in goods in shops, offices conducting commerce, food and beverage services, accommodation services, warehouses, etc, but excluding the water used by schools, hospitals, universities, government offices, fire fighting, and so on, which constitute the institutional, or so called public water use category. A general criterion for judging whether an establishment belongs to the commercial or institutional water use category is by determining if it is a profit-maker or social welfare organization.

It is well recognized that less effort has been devoted to analysing factors underlying commercial water demand than water use of domestic or industrial users (Jones, Boland, et al., 1984; Kindler, 1984, p156-157). In China, commercial water use is still analysed together with the residential and institutional water use; and even in the definition of residential water use, commercial and institutional water uses are included (Yang, Ren, et al. 1984). The reasons for putting commercial water use into the residential water use category may be generalized as: firstly, commercial establishments use water primarily for sanitary and hygienic purposes, which are similar to that of residential water use, so that it may be affected by some of the same factors that influence residential water use; secondly, commercial water use takes a small proportion compared to residential water use: usually only about 10% to 25% of residential water use in the Chinese cities; and thirdly, it is not easy to separate water use by some small businesses from that used for domestic purposes, since they may share the same building or even a common water tap.

However, since 1980s, different prices have been established for commercial water use from that applied to residential water use in many Chinese cities. The price of commercial water use is much higher than that of institutional and residential water use. For instance, the price of commercial water use applied in 1992 by Lanzhou Water Company was 0.5 yuan per cubic metre, compared with the price of institutional and residential water use at 0.25 yuan per cubic metre. The quantity of water used by commercial establishments is available from water company's statistics. This creates the possibility to analyse commercial water use separately. However, institutional water use is still mixed with the residential water use category due to the same price that is charged.

If data is available, it is clearly desirable to analyse the commercial water use separately. Although some of the factors affecting commercial water use may be the same as those influencing residential water use, the importance of these factors in commercial water demand forecasting may be different from their importance in residential water demand forecasting (Prasifka, 1988). And particularly, the dramatic development of market economy in China since the economic reform has caused much faster increase in commercial water use than in residential water use. In Lanzhou city, for example, the commercial water use increased 71.7% from 1986 to 1990 compared to a 14.2% increase in residential water use.

Theoretically, factors affecting commercial water use might include those variables representing the scale of establishments, management issues, techniques, social customs, physical environment, and so on. The factor which basically determines the demand of commercial water use should be the scale of the commercial establishments, which may be indicated by numerous variables such as the number of people served, number of employees, sales volume, tax revenue, gross or sales area of the establishments, etc. The effects of other factors from the aspects of management, income level, technique, custom, climate, and so on, can be reflected in the intensity of commercial water use, i.e. from the fluctuations in per customer, per employee, per unit sales volume, or per unit sales area water use over space and time.

Since the unavailability of data, especially long time-series data, is still a major problem in commercial water use study, limited quantitative analysis was undertaken in this chapter, combined with general qualitative assessments.

7.2 THE SCALE VARIABLES AND COMMERCIAL WATER USE

Theoretically, it may be said that the larger the scale of commercial establishments, the more the commercial water demand. The scale of commercial establishments may be proxied by the scale variables like the number of people or customers served, number of employees, sales volume, gross or sales area, etc. There should be some close relationships among these variables. Kim and McCuen (1979) showed that some close correlations exist between sales area and gross store area, between the number of employees and the gross area; and a good correlation seems to exist between the number of employees and the number of customers, for department stores having similar economic functions. Under different conditions, at different levels of aggregation or in different ways of aggregate, for example, the correlations between any two of these variables may be more or less different. The relationships between commercial water use and any one of the scale variables could also similarly differ to a greater or less extent.

7.2.1 Number of Customers and Urban Population

The number of people or customers served may be a better indicator of water use for some kind of commercial establishments where each customer consumes a certain amount of water, like restaurants, barbershops, bathhouses, and so on. For example, the water use quotas set for these establishments in Chinese cities are 15-20 litres per customer per service for restaurants, 10-15 litres per customer per service for barbershops, and 65-180 litres per customer per service for public bathhouses, in which the variations depend on the quality of services and facilities (Yang, Ren, et al., 1984). The problem of using the number of customers served as an indicator of commercial water use in China is that there are no available regular records about it, whether in terms of individual commercial establishments or the commercial establishments in a city in aggregate as a whole. Therefore, the number of customers served will not be a good predictor in forecasting commercial water use, because the number of customers themselves are not available as a statistic. In an aggregate commercial water demand forecast, a convenient alternative proxy variable often thought of, is that of urban population. As it is used in the residential water forecast, the total urban population may be chosen as the basic variable to determine the demand for commercial water instead of the variable of number of customers.

To have a look at how close the relationship between commercial water use and urban population is, regression analyses were undertaken based on the limited data obtained. From Lanzhou Water Company's statistics, commercial water use from 1986 to 1990 is available. Because the time-series is too short, data of commercial water use by the four districts is used instead of total urban use, in which data used by two of the four districts are mixed. Hence, fifteen pairs of data are obtained and used in a single regression analysis between commercial water use and number of population. The result is shown in Figure 7.1, and an equation obtained is:

$$Q_c = \underset{(549.8062)}{-4047.793} + \underset{(0.0015)}{0.0232}\, P_p \tag{7.1}$$

in which, Q_c is the quantity of annual commercial water use in ten-thousand cubic metres; P_p is the number of urban population in persons; and figures in brackets are the standard errors of estimated intercepts and slope of the equation.

The correlation coefficient r obtained from the analysis is 0.974, and R squared is 0.949, both of which are unexpectedly high.

Using the logarithm form of both the dependent and independent variables in Equation 7.1 to undertake the same regression analysis, the result obtained is:

$$\underset{}{\mathrm{Log}(Q_c)} = \underset{(0.8344)}{-9.152} + \underset{(0.1510)}{2.291}\,\mathrm{Log}(P_p) \qquad (7.2)$$

So, an approximate population elasticity of commercial water use resulted from this study is 2.3.

It may be questioned whether or not the result derived from inter-district cross-sectional data can be applied to the aggregate urban area as a whole. By analysing the only five pairs of data of the total commercial water use and urban population in Lanzhou city, the strength of the correlation is nearly as high as that obtained in the inter-district analysis (see Figure 7.2). However, it should be pointed out that the small number of cases being analysed may greatly contribute to the extreme high correlation coefficients obtained, either in the inter-district or city-wide analysis.

A large city that plays a role as a regional commercial centre, not only serves the residents inside the city, but also partly serves the population in its hinterland. According to urban geographic theory, the bigger the city, the larger is the surrounding area and population commercially influenced or served by it. Therefore, urban commercial water use should not only be affected by the urban population itself, but must also be partially related to the population of the surrounding area influenced by it. There are some evidences that may be identified to support this point.

Firstly, per capita residential water use (including commercial and institutional water use) in large Chinese cities is much higher than those in small and middle size cities. Twenty-two large cities around the country were randomly chosen, of which eleven cities are in the northern part of China, and another eleven are in the southern part. The average per capita residential water use of these twenty-two large cities was 127.6 litres per capita per day (lpd) (Table 7-1). Meanwhile, twenty-four small and mid-size cities, of which twelve are located in the north and another twelve in the south, were also randomly selected. The average per capita residential water use of these small and mid-size cities was 65.4 lpd, which is only about half of the amount of per capita residential water use of the large cities (Table 7-2). It could be argued that the difference in water use is mainly caused by difference in living standards between the large and the small or mid-size cities, including factors such as availability of water, daily-life custom, etc. However, an important cause might also come from the commercial sector which consumes a larger portion of water in large cities than in mid-size and small Chinese cities, because there are much more commercial establishments in these large cities.

Secondly, from the value scattering in Figure 7.1, although the correlation coefficient resulted from the liner regression has been as high as 0.974, it may be suspected that a power line can be fitted as well. Thus, a linear regression analysis between commercial water use Q_c and logarithm form of urban population $Log(P_p)$ was undertaken. The correlation coefficient r resulted is 0.969, which is almost as high as that obtained from the linear regression analysis between Commercial water use Q_c and number of population P_p (see Figure 7.3).

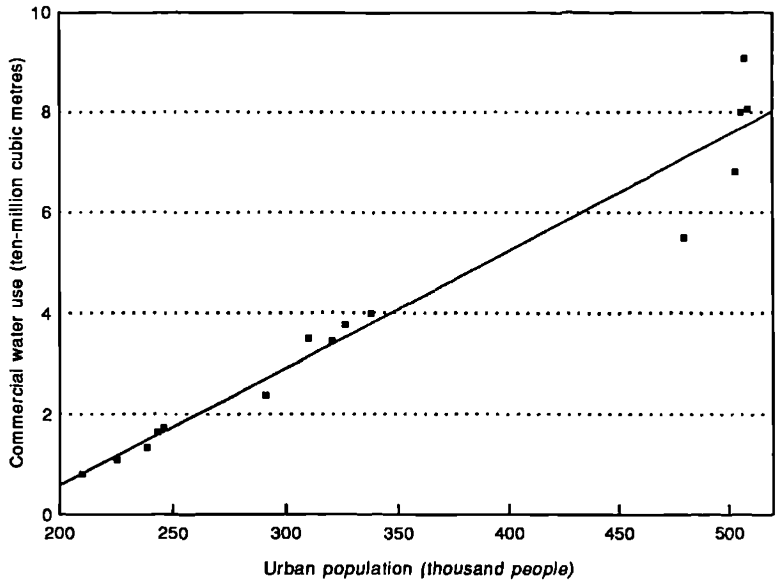


Figure 7.1 Commercial water use and urban population (inter-district) (Trend)

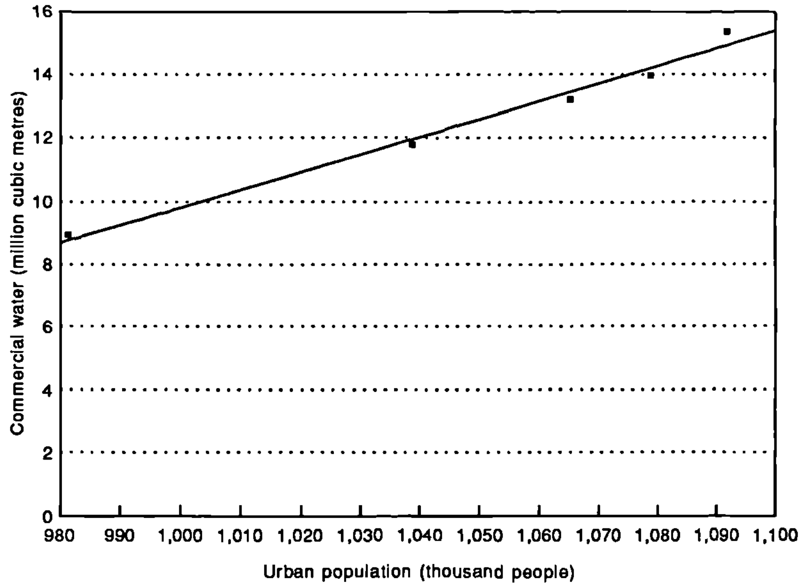


Figure 7.2 Commercial water use and urban population (whole city) (Trend)

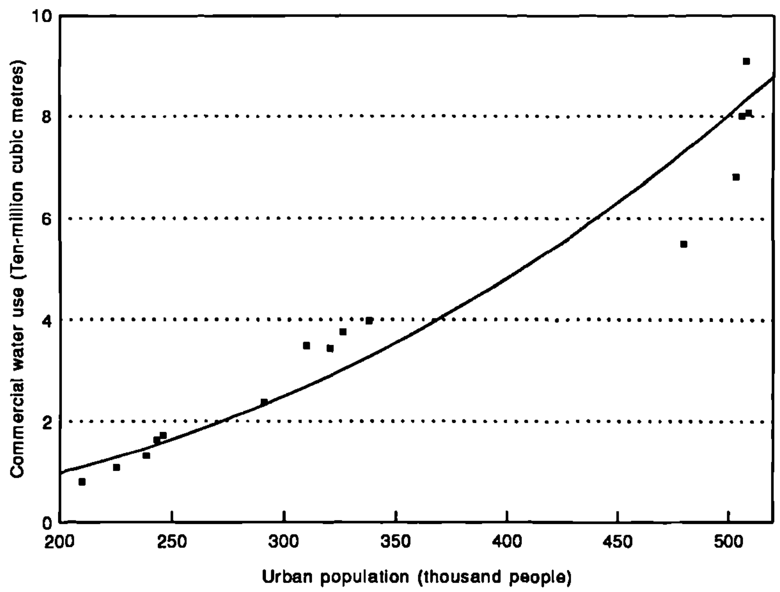


Figure 7.3 Commercial water use and urban population (inter-district) (Power)

From the above evidence, it might be argued that urban commercial water use is not linearly proportional to the urban population. A power relationship is more likely to exist. Applying the distinction made between factors affecting water demand and water use intensity, the number of urban population may be recognized as a factor affecting commercial water demand as well as intensity. In other words, not only the total commercial water demand, but the per capita commercial water use is also influenced by the size of urban population. Therefore, the relationship between commercial water use and urban population might be different from the relationship which existed between residential water use and the population. For this reason, it would be necessary to separate commercial water use from the residential water category in the urban water demand forecasting.

Table 7-1 Per Capita Daily Residential Water Use in Large Cities of China

Cities in North	Daily water use litres/capita/day	Cities in South	Daily water use litres/capita/day
Harbin	88	Guangzhou	235
Changchun	88	Fuzhou	174
Shenyang	138	Shanghai	180
Tianjin	79	Changsha	162
Beijing	196	Hangzhou	114
Taiyuan	121	Wuhan	140
Zhengzhou	160	Nanjing	116
Luoyang	127	Nanchang	122
Xian	130	Chengdu	88
Hefei	75	Chongqing	101
Urumuqi	105	Kunming	70
		On average	127.6

Source: Yang, Ren, et al, 1984, p47.

Table 7-2 Per Capita Daily Residential Water Use in Small and Mid-Size Cities of China

Cities in North	Daily water use litres/capita/day	Cities in South	Daily water use litres/capita/day
Mudanjiang	83	Zhanjiang	166
Jinzhou	41	Sanshui	100
Chengde	32	Yueyang	70
Zhangjiakou	57	Jinshi	64
Dangshan	39	Suzhou	60
Fushun	65	Nantong	64
Qinhuangdao	52	Yangzhou	78
Tongxian	54	Zhenjiang	90
Baoding	33	Zigong	63
Cangzhou	41	Neijiang	56
Handan	94	Nanchong	50
Xingtai	48	Xiangtan	69
		On average	65.4

Source: Yang, Ren, et al., 1984, p47-48.

Furthermore, when the number of urban population is used instead of number of customers in forecasting commercial water use, another factor which should be concerned is the level of income or expenditure. If some other scale indicators of commercial establishments are used, the factor of income level may be excluded, because its effect has already been completely or partly included. For example, the number of customers that visit commercial establishments may be a function of the number of population and the income level of these people. This is to say that number of population is only a partial indicator of commercial establishments' scale rather than a complete one. For performance as a complete indicator of the scale of commercial establishments, the income level and number of urban population should be all considered as factors affecting per capita commercial water use, when number of urban population is used as the factor affecting the demand for commercial water use.

7.2.2 Other Scale Variables

The number of employees may be a better predictor of commercial water use when it is used in association with water use in offices, because water is mainly used by employees for domestic purposes in this kind of commercial establishments. Post offices, branches of banks, and bookshops may also be classified into this category. The water use quota set for offices in China is 10 to 25 litres per employee per shift. When analysing commercial water use of similar commercial activities that do not necessarily belong to the office group, the number of employees may also be used, like the IWR-MAIN model, in which employment in the commercial sector was used as the predictor of commercial water use with adjustment for price elasticity. Due to the significant variation in per employee water use across activity groups, twenty-three special commercial and institutional employment categories were listed, and spaces for twenty-seven additional user-specified commercial categories were given in the IWR-MAIN model (Davis, et al., 1987). Since data on commercial water use in different activities in Chinese cities was not available, it is not possible to undertake a detailed analysis. It seems that a good relationship does not exist between the total commercial water use and the number of employees when Lanzhou city is considered as a whole, from the analysis of only a few years' data.

McCuen, Sutherland, and Kim (1975) suggested that gross area and sales area could be used as predictors for commercial water use. The data that they analysed was the water use in shopping centres, department stores, and mall shops, which involved similar economic activities. They also suggested that a water-use relationship should be derived for each four-digit SIC category, which is the commercial, industrial, and institutional establishment's classification system adopted in America, because the accuracy provided by relationships derived for two-digit and three-digit SIC categories did not appear to be sufficient for commercial water forecasting. The sales area and gross area are not available to assess and predict commercial water use in China at present, even in the issued water use quota for the commercial establishments. An alternative that is found to be used is the number of beds which was used in defining the water use quota for hotels and similar commercial establishments.

The sales volume and tax revenue should be predictors of commercial water use, but they have not been used in the literature possibly due to their drawbacks: unavailability data, fluctuating prices of the commercial goods and services, etc. (McCuen, et al., 1975).

In China, since no research on commercial water use has been undertaken, it is difficult to say which variable is the best predictor for forecasting commercial water demand. What can be suggested here is that it obviously depends greatly on each special case being studied, although data availability is the biggest obstacle.

7.3 THE STRUCTURE OF COMMERCIAL ESTABLISHMENTS

The structure of commercial establishments is defined as the proportional composition of different types or categories of commercial establishments in a given area. The change of the structure of commercial establishments might cause a change in the commercial water use because of the significant variation in commercial water use across different activities. When the analysis or forecast is undertaken at a very disaggregate level, the structural factor has already been taken into account by counting the changes of the scale variables for each category of commercial establishment. Therefore, the structure of commercial establishments can be dealt with as a problem of disaggregation.

As discussed previously, disaggregation is troublesome in terms of data collection as well as projecting the value of the predictors and the relevant variables. Only where sufficient data of an adequate quality is available, can a disaggregate model produce more accurate and useful forecasts than the simpler, aggregate models (Wilson & Luke, 1990). In terms of the data availability of commercial water use and its predictors, it is very difficult to use a disaggregate model in China at the moment. The only available data is the total urban or district commercial water use from the statistics of some water supply companies. Employment in the commercial sector is merely classified into three categories in the available municipal statistics: trade in goods in shops, food and beverage services, and other services. The water use quota established for varied commercial establishments may be adopted in somewhat disaggregate commercial water forecasting, but it would not be as reliable as that based on the analysis of actual water use data of a special urban area studied.

Changes in the patterns of commercial establishments, for example the transition from a neighbourhood-oriented commercial economy to the regional-oriented commercial economy, may also be treated as changes of the structure. The influence of this kind of structural change may be considered by just estimating its effect, and/or by referring to the effects founded somewhere else.

7.4 OTHER FACTORS AND THEIR EFFECTS

Besides the scale and structural factors that affect commercial water use, factors that could influence residential water use i.e. pricing policy, regulations, educational campaigns, supply costs, and changes in technology, could also influence commercial use. However the importance of these variables in commercial water-demand forecasting is different from their importance in residential water-demand forecasting (Prasifka, 1988).

As pointed out by Kindler, et al. (1984, p156-7), although no satisfactory studies have reported on the responsiveness of activities in the commercial sector to metering and water pricing, it seems responsible to assume that there would be some response. However, since the users (often employees) do not pay the bill, the incentive to conserve is indirect, often from management policies and/or municipal regulations. Therefore, one should expect a some-what less marked response to metering and water pricing for commercial water use than in residential water use. Similarly, regulations and education campaigns for water conservation would have less effect in commercial water use than in residential and industrial water uses.

Technological improvements in water-use facilities towards saving water may have the same effect as that in residential sector, since the major portion of commercial water use is for domestic purposes. On the other hand, technological advances made in the commercial services sector may cause the dramatic increase of commercial water demand, for example water use for air conditioning may greatly increase in Chinese cities in a foreseeable future.

The impacts of physical and social custom factors such as climate, religion, etc. may be neglected in forecasting urban commercial water demand, when the forecast is based on a model derived from analysing the historical or investigational data of commercial water use from the same area as that projected, and the forecast is made for a relatively long-term rather than a daily or seasonal variation. This occurs because these variables might mainly make a contribution to the spatial variation of commercial water use. The climate variable may cause the day to day variation in commercial water use, as it does to residential water use. Taking the year as a whole, the impact of annual changes of climate may be not significant for commercial water use. Social customs change very slowly so that their influences might be insignificant also.

7.5 SUMMARY

Three categories of factors that may have an impact on commercial water use are analysed in this chapter. The scale factors are treated equally as the factors affecting the demand for commercial water. Due to these factors are closely related to each other, in practice it might be sufficient to choose one of them in the forecasting model, depending upon the availability of data and the special case being studied. When urban population is used instead of number of customers in forecasting commercial water use, attention should be paid to income level and number of population which should be all related to the per capita commercial water use simultaneously. The structure of commercial establishments can be taken into account by introducing disaggregation into the forecast process. However, it is not an easy option to take. Other factors can be treated as the factors affecting the intensity of commercial water use. Their impacts on commercial water use may be similarly estimated as their function on residential water use, but might be less important.

In conclusion, commercial water use in China is a field that has not been touched by researchers up to date. To reveal the determinants and the relationships between them and commercial water use needs much more research. Research is also constrained by the absent of or very limited availability of data, which cannot be easily overcome at the moment.

Chapter Eight
POLICIES AND URBAN WATER USE: AN OUTER LAYER PERSPECTIVE

8.1 INTRODUCTION

In the previous chapters, the impacts of various factors that directly influence urban water use are analysed. Extending the area of interest wider, it is not difficult to find that water demand is also influenced by some relevant policies, especially some national policies. Changes in the basic factors affecting the demand for water, i.e. urban population, industrial scale, commercial scale, and area of land irrigated, depend to a large extent on the population policy, regional economic development policy, urban policy, and so on. In many circumstances, the factors analysed are only the predictors, but the relevant policies are really the major causes of change in these factors. Therefore, knowledge of these policies and their influence is a necessary part of approaching forecasting-related problems. In the following sections, a general background to major Chinese policies that have influence on urban water demand is presented.

8.2 CHINA'S POPULATION POLICY

The traditional opinion about children in China is "the more children the happier", which has been popular for thousands of years. Before the middle of this century, although the birth rate was high, the population growth was not very great because of the high infant mortality rate and short life expectancy, due to the poor hygienic and health treatment facilities. The Chinese population only reached 540 million in 1949. Since the establishment of the People's Republic of China, the improvement to hygienic conditions and advances made in medical science have greatly contributed to expanding the life expectancy and reducing the mortality rate. Before 1949, the average life expectancy in China was 35 years; by 1987 it had increased to 69.5 years. The mortality rate has dropped from 20 per thousand before 1949 to 6.77 per thousand in 1987; and infant mortality has fallen from an average of 92.55 per thousand during 1944-49 to 22.4 per thousand for the years 1985-87 (Jing Wei, 1992). The pattern of China's population growth has changed from the previous "high birth rate--high mortality--slow growth" to the pattern of "high birth rate--low death rate--fast growth" (CASS, 1989).

The problem of China's population was first realized by the Chinese scholar Ma Yinchu in his book "New Population Theory" published in 1957. However, his opinion was seriously criticized at that time. In 1971, the Chinese government recognized the problem associated with its population so that family planning was included in the country's Fourth Five Year Plan (1971-1975) for the first time. The maximum recommended family size was two children in the cities and three or four in the countryside in the mid-1970s. In 1978, the population policy was regarded as something of strategic importance to "China's Four Modernizations". Since 1979, the government has advocated a one-child limit for urban couples; encouraged the rural couples to have one child, or a large age difference between the two children allowed; and allowed additional children for special situations.

The implementation of the family planning policy has dramatically reduced the population growth rate. The country's population birth rate was reduced to 21.87 per thousand during 1972-1979, and 19.53 per thousand during 1981-1984, compared to 36.19 per thousand from 1962 to 1971 (CASS, 1989). The average number of births per woman fell from 5.81 in 1970 to 2.2 by 1991. Based on a projection at the birth rate in 1970 (33.43 per thousand), the family planning policy in China embarked on 20 years ago has resulted in 260 million fewer birth (Jing Wei, 1992). The one-child policy enjoyed much greater success in urban than in rural areas. Today, most of the young couples in urban areas have one child. Only those who have twins, or a disabled child, can have more than one child. There were compelling reasons for urban couples to limit their family size, even without state intervention. Raising a child required a significant portion of family income, and in the cities a child did not become an economic asset until he or she entered the work force at age sixteen. Couples with only one child were given preferential treatment in housing allocation. In addition, because city dwellers who were employed in state enterprises received pensions after retirement, the sex of their first child was less important to them than it was to those in rural areas (Federal Research Division, 1988).

However, the current birth rate in China is not as low as originally expected. The national population net growth rate in 1986 was 14.1 per thousand, which was much higher than the target of 12.5 per thousand set in the China's Seventh Five-Year Plan (1986-1990). Thus, China's population had reached 1143.33 million by the end of 1990 (The State Council, 1992), which was 30 million more than what was planned at 1113 million. This occurred because China had a very large population base, a large number of women in their child-bearing age, particularly the large generation born during 1962-1971 which are now marrying, and the large rural population (74% of the total). In 1992, the State Council issued a new planned population growth rate for the country and each of its thirty provinces, municipalities, and autonomous regions, for the periods 1990-1995 and 1990-2000. According to this programme, the average population growth rate of the country should be 12.46 per thousand during the period from 1991 to year 2000, while a higher growth rate (14.23 per thousand) was set for the first five years (The State Council, 1992).

According to a forecast made by demographic experts, if China consistently implements its current family planning policy, the population in the mainland will be 1.5 billion by 2025, but by 2045-2050, its population growth will come to a standstill (Jing Wei, 1992). Therefore, until the mid of next century, China will still face a population increase.

8.3 CHINA'S REGIONAL ECONOMIC DEVELOPMENT POLICY

China is a country with a large area of 9.6 million square kilometres. From north to south, and west to east, the physical, social, and economic environment is quite different from place to place. In terms of the economic environment, it is commonly accepted today to classify China into three economic regions: Eastern, Central, and Western economic regions (see Figure 8.1).

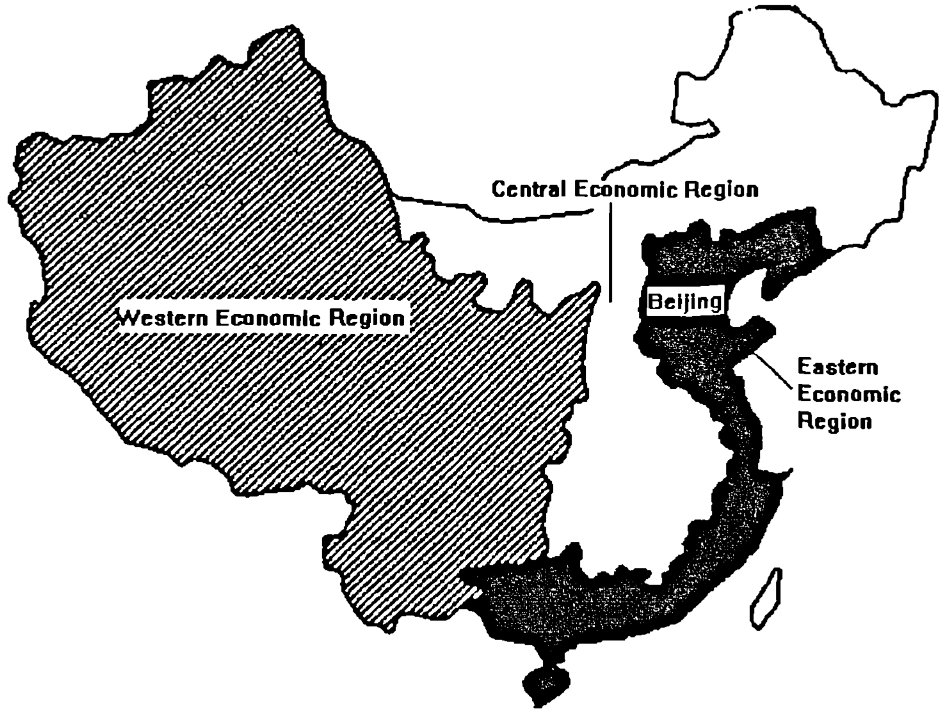


Figure 8.1 Location of the Three Economic Zones of China

From the 1950s to 1970s, Chinese economic policy was mainly intended to promote regional equality or balance. Since more than 70% of the industry was found in the narrow coastal area of eastern China before 1949, during the period of First Five-year Plan (1953-1957), the state mustered nationwide forces to complete 156 large projects, which helped preliminarily change the economic layout which held lingering colonial remainders from old China. In the 1960s, efforts were pooled to set up industries in the hinterland areas, changing the layout where by industries were concentrated in the coastal area (Zou Jiahua, 1992). Between 1953 and 1980, the state investment in construction in the hinterland made up 57.8% of total national investment in construction, compared to 37.1% of state investment in the coastal areas (Wang Haibo, 1991).

Since 1979, Chinese regional economic policy has shifted the development focus to the coastal area or the Eastern economic region. In 1979, the Chinese government decided to set up the special economic zones (referred to hereafter as SEZs) in Shenzhen, Zhuhai, and Shantou in Guangdong province, and Xiamen in Fujian province. The main purpose of setting these up was to draw capital investment from foreign businesses, overseas Chinese and compatriots in Hong Kong, Macao, and Taiwan by using preferential policies (CSSA, 1989). In 1984, 14 coastal port cities (referred as OCCs hereafter) were opened to foreign investment. In 1985, China opened three large triangular coastal areas as foreign investment and economic development zones. And in 1988, again, China extended the outward-oriented economic strategy to the entire 2500 mile long coastal belt, covering 284 cities and counties, about one-fifth of the national population and 3.3 per cent of the land mass (Chen X., 1991). In the Seventh Five-year Plan (1986-1990), the Eastern coastal region was planned to develop into a modern high-technology industrial and commercial region with an emphasis on the four SEZs and the 14 OCCs; the Central and Western region were planned to develop into the energy, mineral, and agricultural bases of the nation (Lo, 1989).

The government has granted varied special rights to the SEZs, OCCs, and other opened areas in order to encourage their economic development. For example, corporation tax is only 15% in the SEZs while it is 33.3% elsewhere; and foreign investors participating in joint ventures in the OCCs enjoy the lower tax rates applied in the SEZs. The preferential policies towards the Eastern coastal region have spurred rapid economic development in this region (Xie and Costa, 1991). As of 1987, the industrial output value of the coastal areas made up 61.15% of the national total, while that of the hinterland made up 38.85% (Wang Haibo, 1991). Noteworthy is the fact that the investment from foreign investors is continuing to increase in the Eastern coastal areas. In the first six months of 1989, for instance, the Eastern economic region absorbed as much as 85% of the total foreign investment in equipment and goods, 14% of which was claimed by the four SEZs alone; by contrast, only 15% of the overall investment went to China's Central and Western economic regions (Chen X., 1991). Therefore, as pointed out by Nathan (1989) the "coastal development strategy" has been the key element in readjusting the spatial patterns of China's regional and urban development.

With the deepening of the reforms, as the Vice-premier Zou Jiahua (1992) described in a speech about the plan for regional economy, the hot spot of investment may gradually move from the southern coast to the northern coast, and from the coastal to the Central region and further to the West economic regions.

8.4 CHINA'S URBAN POLICY

Historically, China has had a low percentage of its population in urban areas, with most of its people concentrated in a few large cities. However this pattern began to change in the early 1980s (Chen X., 1991), mainly resulting from the change in China's urban policy and current reforms.

During the period from 1957 to 1978, partly because of the implementation of the regional balance policy, the number of Chinese cities almost recorded little change. Reducing the difference between urban and rural areas was an important political target from the late-1950s to the mid-1970s in China. In order to restrain urban growth, from 1968 to 1976, around 17 millions of urban youths were sent to the countryside (Kirkby, 1985, p38). Since 1978, along with the opening policy and reforms, China has generally adopted the "growth pole strategy", which is intended to encourage economic development by increasing the number of "growth poles" or cities. Meanwhile, facing various problems in the large Chinese cities, short of accommodation, overcrowded transportation, etc., the State has formulated and implemented a new guiding principle for urban development, namely, the principle of "controlling the sprawl of large cities and developing medium-sized cities and energetically boosting the development of small ones" (CSSA, 1989, p611-14).

The efforts made by the Chinese government to enforce the policy of rigourously controlling the expansion of large cities, rationally developing medium-sized ones, and vigorously building up small cities, have largely been successful (Chen X., 1991). Large cities comprise, according to the classification of the State Statistical Bureau, all cities with a population greater than 0.5 million, medium-sized cities are those with a population between 0.2 and 0.5 million, and small cities with less than 0.2 million. From 1980 to 1991, the number of large cities increased by 16, from 45 to 61, compared to that of medium-sized cities which increased by 51, from 70 to 121, while small ones increased by 189, from 108 to 297 (see Table 3-3). The increase of urban population in large cities is mainly attributed to the return of youths previously sent to the countryside, and natural growth because of the large initial base.

The current reforms in both rural and urban areas have had a particularly strong impact on population movement, contributing to the floating population in Chinese cities. The floating population may be defined as people who live in a city, temporally or permanently, without obtaining an officially approved position as a citizen of the city. There are no available official statistics on the urban floating population. According to some researches (Chen X., 1991; Pannell & Torguson, 1991), the floating population in some Chinese cities amounted to 10-20% of their official resident population. The current movement of population from rural to urban, and from hinterland urban to coastal urban, is centrally related to private, collective, or joint venture industrial and commercial activities. The increased mobility of population movement is resulted from policy modifications and from the emerging reality of the far-reaching changes in the Chinese economy since 1978 (Pannell & Torguson, 1991).

On the other hand, the phenomena of a floating population is related to the Chinese urban resident management system. The movement of population, especially from rural to urban areas, is rigorously controlled by urban resident registration management, through a concomitant urban allocation system which allocates daily-life necessities and services, like housing, food, education, and so on (Kirkby, 1985, p25-32). Along with the development of market economy, the restrictions from the administrative allocation system about necessities and services is becoming increasingly less powerful. However, it is still difficult for people who migrate from rural area, or even a city, to become an official resident of another city. Particularly in the large Chinese cities, the resident registration control is very rigourous under the current urban policy of controlling the sprawl of these cities. Thus, the floating population, or the number of people who have moved into cities without becoming official citizens, is increasing.

8.5 SUMMARY

In this Chapter, Chinese policies related to population, regional economic development, and urban development, and their implemented effects were reviewed. The unique family planning policy in China has achieved great success since its implementation from the beginning of 1970s, in terms of its effect in controlling the growth of China's population. The change of focus in regional economic development policy from "regional balance" to "growth poles", and to the eastern coastal areas combined with the "open door" policy, is reshaping the regional structure of Chinese economy. The urban policy, which is intended to rigourously control the expansion of large cities, rationally develop medium-sized cities, and vigorously develop small cities, has been basically successful. However the reforms have resulted in increased mobility of population and a large number of floating population in the Chinese cities.

It is not difficult to appreciate from the above analyses that these policies directly influence some important factors affecting the demand for urban water use, like urban population, scale of industrial activity, scale of commercial activity, and so on. Some knowledge of these relevant policies and their influences on factors affecting water use is essential for forecasting urban water demand. Besides these national policies, some policies instituted by city governments may have more direct effects on their urban water use.

PART II

MODEL BUILDING FOR FORECASTING LONG-TERM URBAN WATER DEMAND

INTRODUCTION

What kind of model is the best for forecasting long-term urban water demand is still a question faced by water resources planners and decision-makers. After looking back over 75 years' experience in water demand forecasting undertaken in the Seattle (Washington) Water Department, DeKay (1985) pointed out that for forecasts of long-time horizons, it is better to use simpler forecasting models and concentrate efforts on devising sets of plausible assumptions for a systematic analysis. It has been widely recognized that the accuracy of a long-term forecast depends, to a great extent, on the assumptions on which these forecasts are made (Makridakis and Wheelwright, 1989, p395). After studying the accuracy of forecasts made over a period of fifty years in the fields of population, energy, economic and technological forecasting, Ascher (1978) even concluded that "core assumptions" were more important determinants of forecast accuracy than the methods used in forecasting. This is due to the fact that long-term forecasts face more uncertainty than short-term forecasts. Furthermore, different people may give priority to different assumptions, when they are used in their forecasts. Therefore, it is necessary for forecasters to state explicitly the assumptions used in their forecasts.

Simplicity and explicitness may be seen as two methodological principles in long-term forecasting. However, they are not a precise answer to the question 'what is the best or a better model?'

After a wide-range comparative study, including forecasts made for the demand of energy, coal, aluminium, air travel market, camera sales, and so on, Armstrong (1978, p372-382) concluded that causal methods, in which an attempt is made to project the variable of concern by reference to other variables that are assumed to control or influence it, are more accurate than extrapolative methods in long-term forecasting. And causal forecasts have been increasingly favoured by utility forecasters (Gardiner and Herrington, 1986, p7-16). In water demand forecasts, it can also be seen from the literature that causal forecasts, including single and multiple coefficient methods, as well as econometric and requirement models, have been more widely adopted in long-term forecasting than any other methods. Causal forecasts are appropriate for large changes in the causal variables, when a good information is available on the causal relationships, and the direction of changes in the causal variables can be accurately predicted.

The hypothesis in this study, as stated in Chapter One, is that causal relationships exist between water uses and factors affecting them, and the aim of the research is to apply the causal relationships derived from the analysis to the building up of a forecasting model. In Part One, much effort has been spent on analysing the causal relationships between various water uses and the factors affecting them, although it is sill a long way to reveal all the relationships completely. Therefore, it has been the intention to apply causal forecast methods to building up the forecast model from the beginning of the research.

Causal forecast is still a broad idea. From the literature, it can be found that various causal forecast models have been developed, and different explanatory variables have been employed in different models. Based on the analysis undertaken in Part One and facing more restrictions in data availability, the question to answer is: what is a more satisfactory model in terms of the Chinese urban situation? To answer this question, apart from the principles of simplicity and explicitness, attention should also be paid to the following three aspects.

Firstly, the distinction made between factors affecting the demand for water and factors affecting the intensity of water use can be applied in constructing the model. Although the commonly used single coefficient method is simple, it ignores the effects of many factors affecting water use. Simplicity is important for model building, but ignoring the existing causal relationships to a great extent is not acceptable. Using the distinction, in addition to the significant factor which is recognized as affecting the demand for water, more factors can be related to per unit water use. This will not necessarily result in too much complexity. If multiple coefficient method is used without implying such a distinction, confusions and complexities might be raised as discussed at the beginning of Part One.

Secondly, most causal forecast models which were built by using the single coefficient and multiple coefficient methods are static models (Howe and Linaweaver, 1967; Young, et al., 1985; Metzner, 1989; etc.). However, forecasting is a time-related issue so that it is better to include the time variable into the forecast model. In practice, the change in some factors is often expressed in terms of increase rates, such as natural population increase rate, annual per capita income increase rate, etc. They are more commonly used indicators/criteria in describing the change in these factors, so that it is more comparable and easier to understand to use the rate terms than to use absolute terms, i.e. to express the change by the difference, without explicitly giving the time period within which the change occurred. Thus, it is useful to combine the time variable into the forecast model, or to describe water demand system as a dynamic system, whether from the perspective of the characteristic of forecast or in terms of the change of the factors considered.

And thirdly, due to uncertainties involved in long-term forecasting, alternative futures, or scenarios, should be concerned in building the model. It is desirable to produce the scenarios systematically from the model developed.

Under consideration of the above conditions or criteria, the method of system dynamic simulation is adopted to build the model. Relying on causal relationships, system dynamic simulation is actually an alternative to the econometric method (King and Telford, 1977). Based on the theory of system dynamics that is greatly contributed by J. W. Forrester (Forrester, 1968, 1976), computer programs, the DYNAMO series, which are very useful and convenient tools for utilizing system dynamic simulation in practice, have been developed for quickly running the simulation models.

Time is a built-in variable in system dynamic simulation so that it is very convenient to present the results of forecast in terms of time. The system dynamic simulation procedure allows alternative forecasts to be obtained easily, quickly, and explicitly by giving different assumptions about the projected value of the explanatory variables and coefficients. Simulation is a formal way of systematically asking and answering the "what if" questions (Meta Systems Inc., 1975).

System dynamic simulation is a step-by-step procedure. The model's structure can be readily understood even if its behaviour is not immediately obvious. Although the projected value of the explanatory variables are often adopted from forecasts made by other specialists, in the system dynamic model, they can be presented more explicitly. Instead of treating them as purely inputs without any further explanation, the system dynamic model can present simple descriptions about the changing process of these explanatory variables. Whether these are adopted from others or not, it makes the forecasting process explicit and clear.

There are three chapters in this part. Chapter Nine is on the methodology, in which the relationship between the existing coefficient methods and system dynamic simulation is explained. Theoretically, there is only one basic causal relationship between water use and a factor influencing it. The relationship may appear in different forms when it is employed in different models. Therefore, the concept of system dynamic simulation employed in this research is not described as a completely new creation, but it is a development from the coefficient methods. In Chapter Ten, the computer simulation model that has been built is described, using the system dynamic language. In Chapter Eleven, applying the system dynamic simulation model, the case study which was carried out is described; and the performance of the model is evaluated.

The causal relationships employed in building the model are derived from the analyses in Part One, in which four water use sectors have been classified and discussed. Thus, the system dynamic simulation model is composed of four subroutines. Its description in Chapter Ten, and its application in Chapter Eleven are made according to the respective four sectors.

Chapter Nine
METHODOLOGY

9.1 A CONCEPTUAL MODEL

Forecasting water demand or requirement by an aggregate water user, which may be a country, a city, an industrial sector in a region, and so on, is to answer the general question of "how much water will be demanded or required by the water user in a future time?" It would become more explicit if the question is split into four interrelated questions:

(1) How much water is currently, or recently, used?

(2) Will the water use in a future time be different from the current or recent use?

(3) If the answer to the second question is "yes", then, what are the motivations (factors) which cause the difference or change? and

(4) How will the factors (motivations) influence water use?

The first question indicates that it is necessary to know the history of water use for forecasting, especially current water use. Without having enough knowledge about current and past water use, it is almost impossible to forecast future water demand properly. The knowledge about current water use includes the amount of water used by different sectors, which are needed to be forecasted separately, as well as the relationships or patterns between water uses and factors affecting them. This kind of knowledge can be obtained from investigation, data collection and analysis. Particularly, regression analysis is a useful tool for explaining the relationships between water uses and the factors influencing them. The more knowledge about current and past water use, the more possible it is to obtain reliable forecasts.

"Things can stay the same, get better, or worsen" (Reid, 1971). Forecasts are often made based on a comparison between the future and current, whether it is stated explicitly or implicitly. Theoretically, the answer to the second question can be "yes" or "no". If a negative answer were given, no further effort would be necessary to obtain the result of the forecast, because the forecast would be the same as the current use. However, in terms of a dynamic system, no "no" answer should be given, or the answer to the second question must be "yes".

Having assessed that the situation is dynamic, the third question is trying to explain why the future water use will be different from the current use. Following the routine of causal analysis, a general answer to the question would be that changes of some factors cause the change of water use. Future demand is only different from past or present demand because of change in society (Gardiner and Herrington, 1986, p1-6). Although it is not very possible to reveal all the factors which cause the change, it is not difficult to identify some predictable factors that will change and influence water use in the future time.

The fourth question is the most crucial one for forecasting, and the most difficult one to answer, especially in terms of mathematical expression. As revealed in Part One, the mathematical relationships or coefficients between water uses and the factors are not consistent. They change with levels of scale, ways of aggregation, and even from one case study to another. The income elasticity obtained from the analyses in Section 4.3, for example, range from 0.01 to 0.44. However, this problem may be partly overcome by setting up the principle of 'respecting the local situation being studied', which means to use the same scale level, same way of aggregation in forecasting as used in analysing and deriving the coefficients. There may even be uncertainties involved in determining the coefficients with regard to this principle. Using alternative futures or different scenarios of the future is another way to deal with this problem.

After answering the four questions, a modelling method may be adopted, a model produced, and the result of forecast is worked out. The step-by-step procedure of answering the four questions may be regarded as a conceptual model of forecasting, as shown in Figure 9.1. When the model is applied, the term 'water use' can be referred to as total water use, or per unit water use, in terms of any kind of aggregate or disaggregate water user.

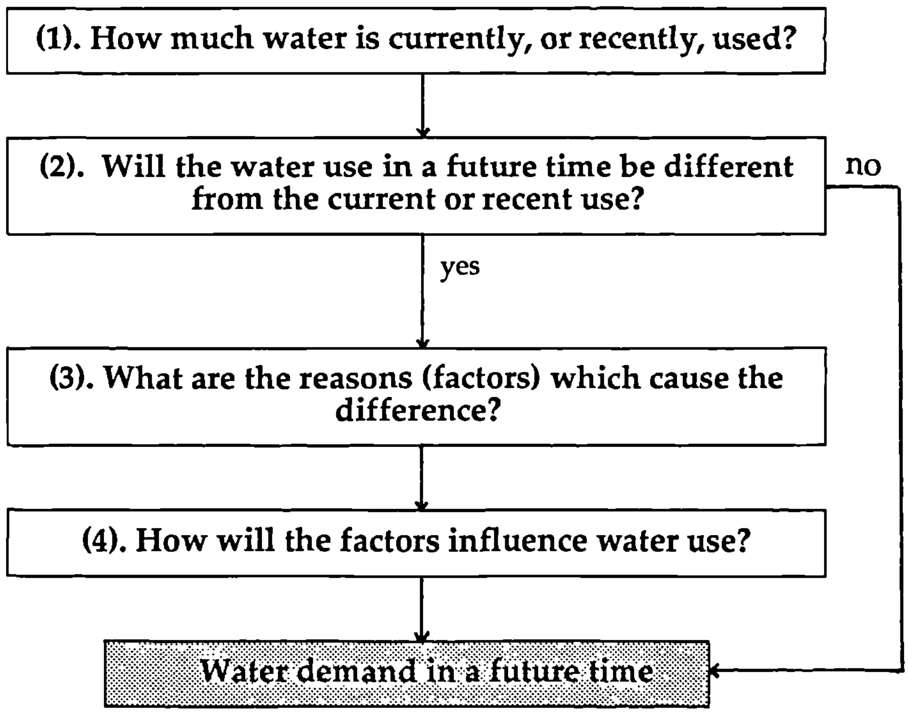


Figure 9.1 A Conceptual Model For Water Demand Forecasting

9.2 A LOGISTIC MODEL

9.2.1 A Simple Adjustment to the Single Coefficient Method

For forecasting long-term water use, the commonly used method is the single coefficient method. As detailed in Section 2.2.3, this method has its advantages and disadvantages. The only explanatory variable X in Equation 2.1 is often an indicator of scale or size of the water use sectors, or it is a proxy of the factors affecting the demand for water rather than those affecting the intensity of water use, as the distinction made in Part One. It is quite reasonable to regard these scale variables as the determinants of water use, but it is not proper to entirely ignore the effects of other factors which are known to affect the intensity of water use.

The coefficient c in Equation 2.1 is supposed to be adjustable with time. However, there is no explicit procedure about how to make adjustments which is suggested by the single coefficient method. In practice, the coefficient is often obtained from regression analysis and/or with subjective adjustments.

Adopting the basic form of the single coefficient method, the coefficient c can be replaced by U, which is a function of some relevant variables that influence the intensity of water use. Then, the form of Equation 2.1 is transformed into:

$$Q = U * X + e \qquad (9.1)$$

in which

$$U = f(X_1, X_2, X_3, \dots) \qquad (9.2)$$

where Q is the quantity of water demanded; U is the per unit water use (per capita, unit value product, etc.); X is the basic determinant variable; and X_1, X_2, X_3, ... are the variables affecting water use intensity, or affecting the per unit water use.

9.2.2 Acquisition of Dynamic Equations

Assuming the current water use is Q_0, and water use in a future time is Q_t, according to the conceptual model, the relationship between them can be expressed by the following simple equation:

$$Q_t = Q_0 + \Delta Q \qquad (9.3)$$

in which ΔQ is the change term of water use from current time to the time t.

Similarly, future per unit water use U_t can be expressed as:

$$U_t = U_0 + \Delta U \tag{9.4}$$

Based on Equation 9.2, and according to the general answer to the third question of the conceptual model, the change term ΔU can be expressed as:

$$\Delta U = f(\Delta X_1, \Delta X_2, \Delta X_3, \dots) \tag{9.5}$$

All the independent variables and the dependent variable in Equation 9.5 can be regarded as changing with time. Thus, a differential equation about the time variable Δt is:

$$\Delta U/\Delta t = f(\Delta X_1/\Delta t, \Delta X_2/\Delta t, \Delta X_3/\Delta t, \dots) \tag{9.6}$$

Let $R_u = \Delta U/\Delta t$

Then $$U_t = U_0 + \Delta t * R_u \tag{9.7}$$

And $$U_t = U_0 + \Delta t * f(\Delta X_1/\Delta t, \Delta X_2/\Delta t, \Delta X_3/\Delta t, \dots) \tag{9.8}$$

R_u might be called the change rate of per unit water use. The concept of change rate is very important in System Dynamics. It may be represented by the differential form of dU/dt.

9.2.3 Application of the Dynamic Form to Linear and Logarithm Form Functions

For residential water use, for example, suppose the following linear equation exists:

$$U = a_0 + a_1 I + a_2 F + a_3 P + \varepsilon \tag{9.9}$$

Where U is per capita daily water use; I is per capita annual income; F is the average family size; P is water price; a_0, a_1, a_2, and a_3 are coefficients, or called parameters; ε is the error term.

At time = t and time = 0, Equation 9.9 can be written as:

$$U_t = a_0 + a_1 I_t + a_2 F_t + a_3 P_t + \varepsilon_t \tag{9.10}$$

And $$U_0 = a_0 + a_1I_0 + a_2F_0 + a_3P_0 + \varepsilon_0 \quad (9.11)$$

Equation 9.10 - Equation 9.11, then

$$U_t - U_0 = a_1(I_t - I_0) + a_2(F_t - F_0) + a_3(P_t - P_0) + (\varepsilon_t - \varepsilon_0) \quad (9.12)$$

So $$\Delta U = a_1\Delta I + a_2\Delta F + a_3\Delta P + \Delta\varepsilon \quad (9.13)$$

And $$\Delta U/\Delta t = a_1(\Delta I/\Delta t) + a_2(\Delta F/\Delta t) + a_3(\Delta P/\Delta t) \quad (9.14)$$

The error term ε is assumed to be a random variable that does not change regularly with time. Therefore, it does not appear in Equation 9.14. Equation 9.14 can also be directly obtained from differentiating Equation 9.9 by the time variable.

Therefore, for the linear function given, a similar equation as Equation 9.8 can be written as follows:

$$U_t = U_0 + \Delta t * (a_1\Delta I/\Delta t + a_2\Delta F/\Delta t + a_3\Delta P/\Delta t) \quad (9.15)$$

If the linear Equation 9.9 is replaced by a logarithm form equation, such as:

$$\ln U = a_0 + a_1\ln I + a_2\ln F + a_3\ln P + \varepsilon \quad (9.16)$$

where the coefficients a_1, a_2, and a_3 can be regarded as the elasticities of the independent variables of I (income), F (family size), and P (water price), respectively.

Then $$U_t = a_0 * (I_t)^{a1} * (F_t)^{a2} * (P_t)^{a3} * \varepsilon_t \quad (9.17)$$

And $$U_0 = a_0 * (I_0)^{a1} * (F_0)^{a2} * (P_0)^{a3} * \varepsilon_0 \quad (9.18)$$

An equation obtained from dividing Equation 9.17 by Equation 9.18 is:

$$U_t/U_0 = (I_t/I_0)^{a1} * (F_t/F_0)^{a2} * (P_t/P_0)^{a3} * (\varepsilon_t/\varepsilon_0) \quad (9.19)$$

Thus,

$$U_t = U_0 * (I_t/I_0)^{a1} * (F_t/F_0)^{a2} * (P_t/P_0)^{a3} * (\varepsilon_t/\varepsilon_0) \quad (9.20)$$

The error term $\varepsilon_t/\varepsilon_0$ might be omitted from Equation 9.20. The remainder is the same form of model suggested by Reid (1971) for long-term macro urban water demand forecasting. The only difference is the variables concerned. The variables considered in Reid's model were precipitation, income, and population.

9.3 SYSTEM DYNAMIC SIMULATION

In system dynamics, the process of calculating the change is based on the theory of integration. It performs the process of integration by accumulating the changes of a variable within specified solution intervals. It is quite similar to that discussed in Section 9.2.2. If the method of integration is used, Equation 9.7 is equivalent to:

$$U_t = U_0 + \int_0^t R_u \, dt \tag{9.21}$$

Then, using the language of system dynamics, Equation 9.21 would be written as:

$$U.K = U.J + DT * RU.JK \tag{9.22}$$

and $$U=NU \tag{9.23}$$

Where:

U is called a level variable;

U.K: new value of the level variable being computed at time K (units);

U.J: value of the level variable at the previous time J (units);

DT: the length of the solution interval between time J and time K (time measure);

RU is called a rate variable, which is equivalent to R_u in Equation 9.21;

RU.JK: the value of the rate added or subtracted during the JK time interval (units/time measure); and

NU: initial value of U.J at time zero, which is equivalent to U_0 in Equation 9.21 that indicates the model at time 0.

Comparing Equation 9.22 to Equation 9.7 or/and Equation 9.21, some differences can be observed. From doing the comparison, some characteristics of System Dynamic and Professional DYNAMO can be revealed. Professional DYNAMO (referred as PD hereafter) is a new version of the DYNAMO series, which is designed for quickly compiling and executing continuous simulations of dynamic systems. Except for following the general principles of system dynamics, as a unique program, it has some special program regulations. As a brief introduction to system dynamics and Professional DYNAMO, the following are presented compared to static models.

(1) The symbols used to represent variables and constants in system dynamic equations are different from those in the analytical equations. In system dynamics, they are often abbreviations that can bear an obvious relationship to the quantity they represent. Using the Professional DYNAMO, quantity names may be from one to seven alphabetic or numeric characters long, the first of which must be alphabetic (Pugh-Roberts Associates, 1986).

(2) In system dynamics, variables are given time subscripts by using a different way from that used in analytical equations to indicate the time of quantity and the order of computation. Since standard computer equipment does not permit the usual subscript notation, the time-script becomes a postscript set off from the quantity name by a decimal point, such as U.K denotes the quantity U at time K, RU.JK denotes the rate change during the interval from time J to time K. Due to the present time at which a variable is calculated is defined as time K, the forthcoming time interval for which a rate is calculated is defined as the time K to L. Thus, RU.KL denotes the rate change during the interval from the current time K to a forthcoming time L.

(3) Level and rate are important concepts in system dynamics. The level variables quantifying the condition of the system at any particular time, and they accumulate the results of action within the system. The rate variables tell how fast the levels are changing, and they determine, not the present values of

the level variables, but the slope (change per time unit) *of the level variables* (Forrester, 1968, p4-5). Level equations are integral equations, like Equation 9.22, which relate a level at the current time to its value at the previous time at which calculations were made and to its rate of change during the interval between calculations. The rate equations state how the flows within a system are controlled.

Parallel with "level" and "rate", in addition, another important concept in system dynamics is "auxiliary". Auxiliary variables give supplementary information attributed to the calculation of rates and levels. Auxiliary equations are simple algebraic functions of levels, rates, and other auxiliary variables at the current time.

(4) In the system dynamic equations, there can be constants and initial values. Using PD, constants are often represented by symbolic names, which will be referred to as parameters or initial variables in the following chapters. Numerical values are given to these symbolic names by constant equations. All level equations must be given initial values at the start of the simulation computation. NU in Equation 9.23, for example, means the value of U.J at time zero. It is presented in a simple isolated equation, which is really like a decoration, but it is different from the way that is used in analytical equations, in which constant term is only a part of them.

TIME is a level variable (subscribed .K or .J) that is built into the PD. Therefore, an initial value should be given to it when the simulation is wanted to start at a desired time rather than zero, for example, year 1986. The simulation runs from that initial value until TIME is equal to LENGTH, which is the value of TIME when the run is to be terminated (Pugh-Roberts Associates, 1986).

(5) There are control statements in the system dynamic simulation model, which specify the length of the interval between TIME.J and TIME.K, the

interval of TIME between the saving of results for later comparative output, the variables selected for output, and comments about variables or equations, etc. The NOTE statement in the PD, is often used to give some detailed information about the meaning of the variables and equations, which make the simulation model readily understandable.

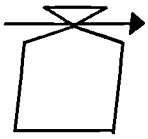
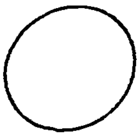
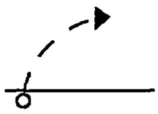
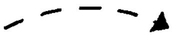
(6) Finally, in order to give a visual description of a system, a flow diagram form is often used. Various equations describe the behaviour of a system in terms of its separate parts. The flow diagram can give a broader perspective, which shows the relationships between these parts. The level, rate, auxiliary, and constant equations, and how they are interconnected, can all be shown in the flow diagram by using some symbols. A level variable is depicted by a rectangle, a rate variable is depicted by a symbol that looks somewhat like a valve, and an auxiliary variable is depicted by a circle. A complete set of flow diagram symbols is included in Table 9-1.

The technique of computer simulation designed for dynamic systems was developed several decades ago. The original DYNAMO program was introduced in 1959. Since then, versions of DYNAMO program have been developed. The Professional DYNAMO that is used in this research was published by the Pugh-Roberts Associates in 1986.

9.4 ESTIMATING THE COEFFICIENTS

After deciding the form of function and model, another important thing in model building is to estimate the coefficients, such as a_0, a_1, a_2, a_3, in the linear and logarithm form equations. Only when the coefficients are settled, has the fourth question in the conceptual model been completely answered. Finding

Table 9-1 Flow Diagram Symbols

	Level
	Rate
	Auxiliary
	Constant
	Flow
	Cause-and-Effect Link
	Source or Sink

Source: Roberts, et al, 1983, p284.

out the function form of the relationship between water use and the determinants has only partly answered the fourth question in the conceptual model.

In practice, the most commonly used method in determining coefficients is regression analysis, either single or multiple regression. Coefficients are conveniently obtained from regression analysis from the historical data. A generally accepted principle is that the higher the correlation coefficient, the more accurate the prediction result. However, this is a conditional statement, which is correct under some conditions or assumptions. In order to make it clearer, here it may be necessary to make a distinction between a measurement model and a forecast model.

A measurement model is a model obtained from analysing actuarial data or records. A forecast model is one used for projecting future demands. The coefficients obtained from a measurement model, are sufficient for forecasting only when two conditions are met:

(1) There is no error in estimating the current relationship; and
(2) There is no change in the relationship over the forecast horizon.

Otherwise, errors may arise when a measurement model is used in forecasting. From the analysis in Part One, it can be found that the coefficients between water use and the independent variables vary with studies at different scale levels, for different places, and for different time periods. Sometimes, the variation of the coefficients is remarkable. As mentioned previously, quite different results about the elasticity of water price and level of income have been reported in the literature. All these features contribute to the difficulty to ensure the first condition that there is no error in estimating the current relationship.

In terms of the second condition, it is quite doubtful to assume that the relationship between the dependent variable and the independent variables will not change over the forecast horizon, especially over a long-term period. The 'long-term' usually implies that time by when significant structural changes will have occurred. One of the recurrent problems of forecasting, as pointed out by Encel (1975, p3), is to utilize historical explanations without projecting them naively into the future.

Therefore, when they are used in a forecast model, the coefficients in the measurement model should be adjusted to represent the conditions expected over the forecast horizon. However, coefficient adjustment is often associated with subjective judgements. So, there is a dilemma in deciding whether or not to adjust a measurement model when it is used for forecasting.

9.5 UNCERTAINTY AND ALTERNATIVE FUTURE

In addition to the uncertainty around the coefficients, there are uncertainties in the causal factors, because the values of these factors in a future time are needed to be forecasted as well. Population, for example, may have several forecasts available simultaneously, made by different organizations or forecasters; or in terms of long-term population increase, a higher, medium, and lower annual population growth rates may be estimated, as is often done in China. It cannot be judged which forecast is more accurate than the others. A method to deal with this kind of problem is to make scenarios of the future, called "alternative futures".

A procedure to deal with the uncertainty of independent variables in water use forecasting was described by Whitford (1972). He used six variables in his analysis. They were regulation, pricing policy, educational campaign, housing trend, supply cost, and technology of consumption. Except for the variable of housing trend that was allowed to have three most possible outcomes, each of the remaining five variables was estimated as two opposite possibilities. Therefore, a total of ninety-six scenarios (2*2*2*2*2*3=96) were obtained from different combinations (see Figure 9.2). The effects of the variables on water use were mainly estimated by using subjective methods. A frequency distribution of the forecast results from the ninety-six different scenarios can be derived. And a range of forecasts, rather than a single number, can be produced (Figure 9.3).

The advantage of Whitford's procedure was that a systematic way was used to work out the scenarios caused by the possible changes of the causal factors. However, he devoted two simple possibilities, only either "yes" or "no", to five of the six variables adopted. That is to say, each of the five factors was assumed to have either a certain effect on residential water use, or have no effect at all. In reality, the problem involved is often not simply "yes" or "no", but "how much". If the "no" answer is given, sometimes, it perhaps have taken an extreme situation into account, rather than a likely occurred event. Thus, a quite wide range of possible outcomes of forecast may be obtained, as reported by Whitford himself (1972).

However, the likely occurred alternatives, rather than the extremes, might be put together, and their frequency distribution may be calculated by adopting the same method as described by Whitford. Following the same idea, forecasts made by different forecasters may be treated equally, and put together to obtain a range of forecasts and to calculate its frequency distribution as well. A major problem involved in this process is to decide what the most likely futures are. Different assumptions may be involved in this issue so that it is both necessary and important to be explicit.

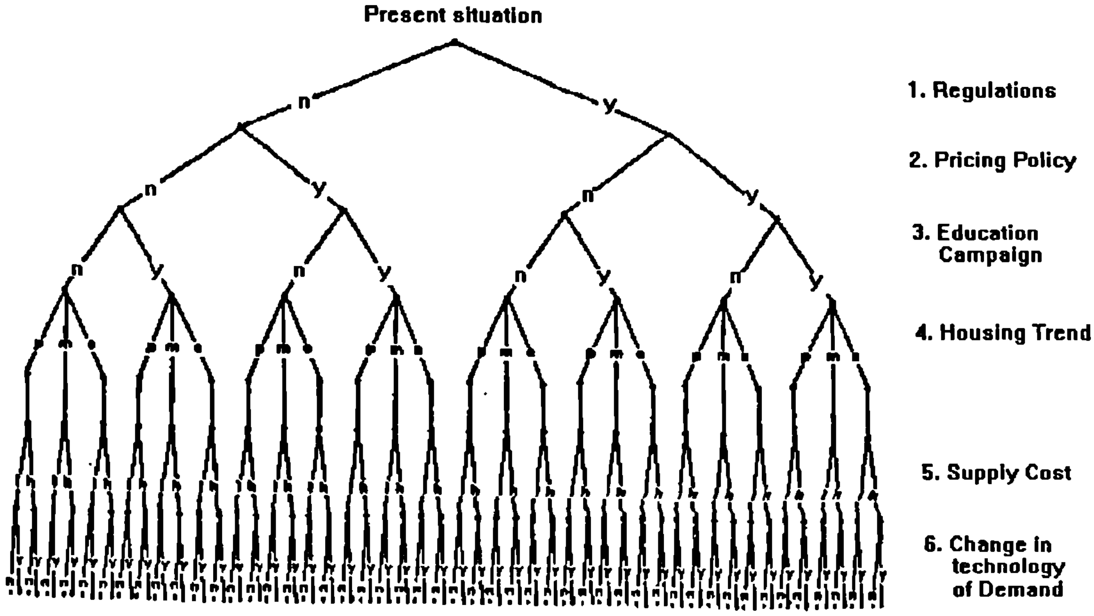


Figure 9.2 Model for forecasting residential water demand. The letters indicate y, yes; n, no; p, present; m, moderate; e, extreme; h, high; l, low.

Source: Whitford, 1972.

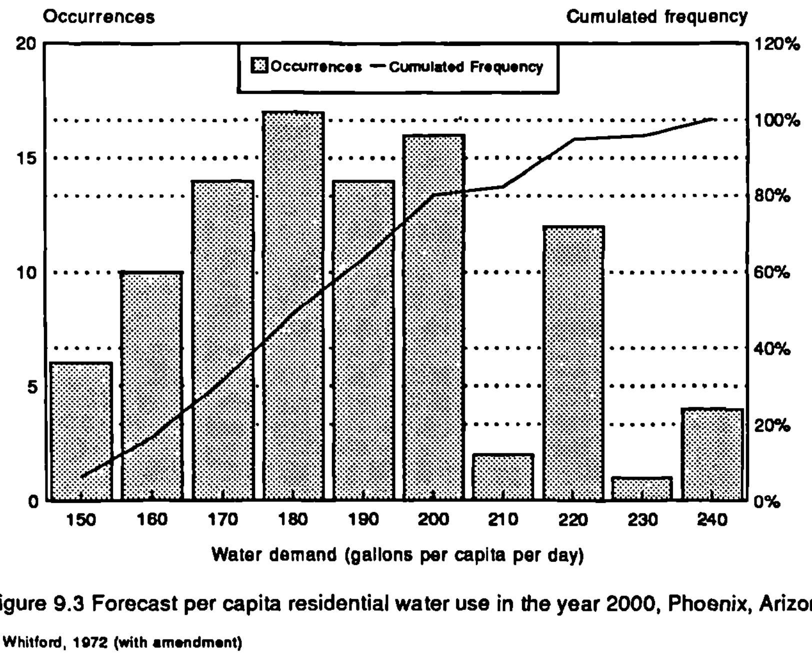


Figure 9.3 Forecast per capita residential water use in the year 2000, Phoenix, Arizona

Source: Whitford, 1972 (with amendment)

9.6 SUMMARY

In this chapter, the methodology used in the following chapters has been presented. The conceptual model described a four-step-procedure for dealing with the problem of water demand forecasting. The logistic model described an improvement made towards the simple single coefficient forecast method, and how to transfer a static equation into a dynamic equation by introducing the variable t into analysis, which were applied to a multiple linear equation and a logarithm form equation. Section 9.3 gave a general description of the system dynamic simulation, which is the tool used in the model building. Coefficient (parameter) estimation is an essential part of the work, but involves uncertainties in terms of method used to estimate it and values adopted for it. Therefore, the concept of "alternative futures" is useful, and the procedures developed by Whitford (1972) to deal with uncertainties are helpful for making a clear presentation of the alternative futures obtained. The methodology described above will be applied in the following two chapters.

Chapter Ten
A COMPUTER SIMULATION MODEL USING SYSTEM DYNAMIC APPROACH

10.1 INTRODUCTION

Based on the analyses in Part One and the methodology described in Chapter Nine, a system dynamic simulation model set for forecasting long-term urban water demand has been built. The variables concerned and the relationships employed in the model are generally derived from the previous analyses based on the Chinese situation. The theory about how to change a static model into a dynamic one which is described in Section 9.2 contributes to make a close connection between the static analyses and dynamic simulation. Then, the technique of system dynamic simulation and the PD software can be smoothly applied.

The system dynamic simulation model is composed of four subroutines: residential, industrial, agricultural, and commercial, which are identical with the classification made in Part One. The four subroutines are described in the following four sections respectively.

10.2 RESIDENTIAL SUBROUTINE

Residential water use, as discussed in Chapter Four, is influenced by many factors. However, restricted by data availability and unknown relationships between water use and some factors, only the factors which have been clearly proven to affect residential water use, are taken into account. In addition to the factor of population, which is treated as the variable affecting the demand for water, another two exogenous variables are concerned in the residential subroutine. They are per capita annual income and average family size, which are related to the per capita daily water use, or the intensity of residential water use. Thereafter, two more adjustment variables are considered: the effect of water conservation policy and public water supply coverage. The relationships between residential water use and these independent variables concerned in the simulation model are described in the following.

10.2.1 Flow Diagram

As a necessary and useful procedure in system dynamic simulation, a flow diagram is drawn to show the components of a residential water use sub-system and their relationships concerned in the model of forecasting (see Figure 10.1).

10.2.2 Equations and Variables

In the residential subroutine, a major equation, which is for annual residential water use, is written as:

$$WREQ.K=PCQ.K*POP.K*365/1000 \qquad (10.1)$$

where:

WREQ: annual residential water use, in cubic metres.
PCQ: per capita daily water use, in litres per capita per day.
POP: numbers of population, in people.

Equation 10.1 is actually the per capita forecast method described in system dynamic language. It is an auxiliary equation in the model.

Like the adjustment made to the single coefficient method described in Section 9.2.1, the per capita water use PCQ is defined as a linear function of per capita annual income and average family size. The equation to present this relationship is:

$$PCQ.K=PCQ.J+DT*(CPAI*RINC.JK+CPAF*RFAS.JK) \qquad (10.2)$$

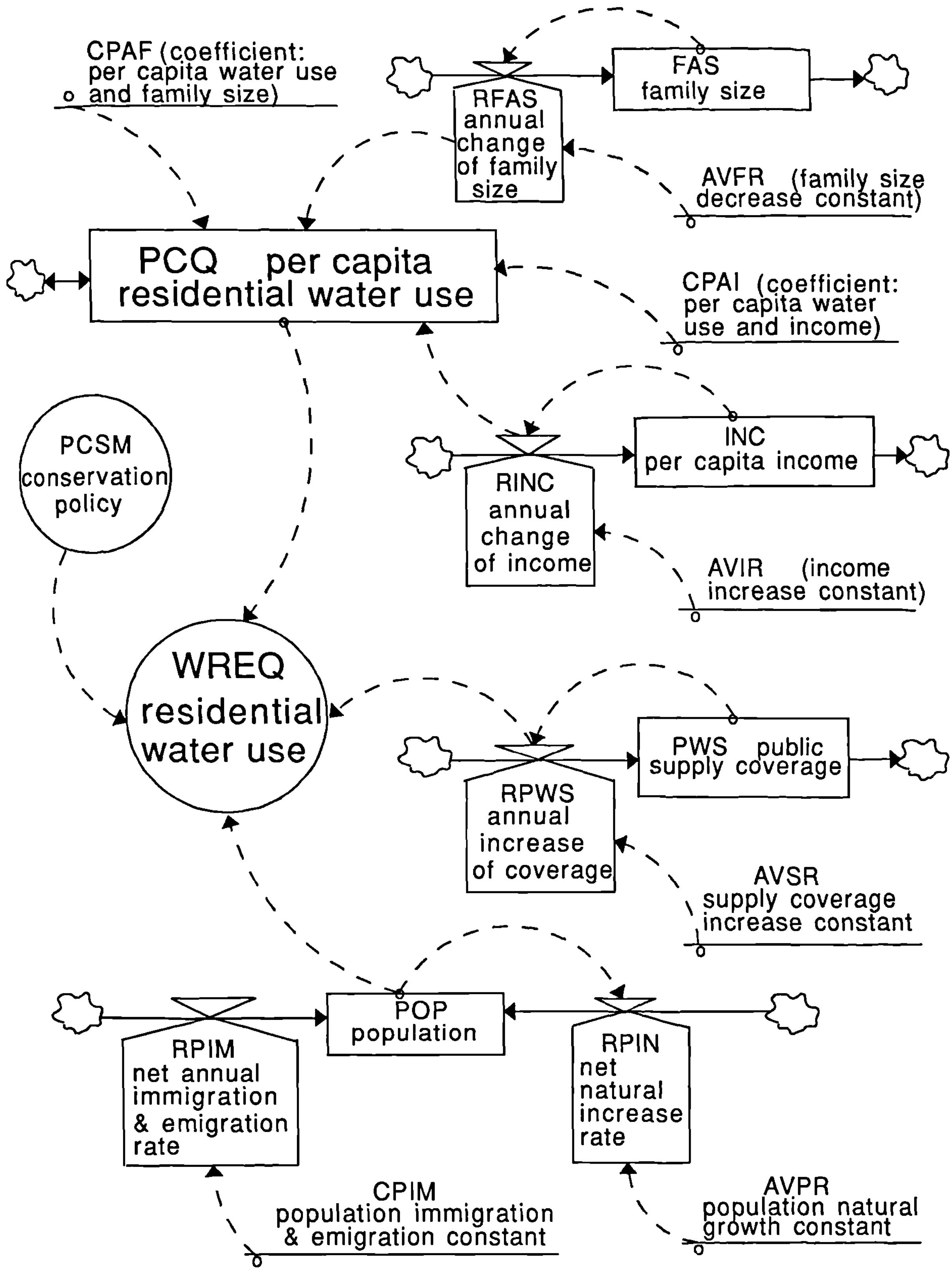


Figure 10.1 Flow Diagram of residential water use

PCQ=NPCQ (10.3)

in which:

PCQ: per capita daily water use, as defined before.

RINC: annual change in per capita income, in yuan per capita per year.

RFAS: annual change in family size, in persons per family per year.

CPAI: coefficient between water use and income.

CPAF: coefficient between water use and family size.

NPCQ: initial value of per capita daily water use.

DT: length of the solution interval between time J and time K. It is set as one year in this study. It appears in every level equation with exactly the same meaning, and will not be repeated again hereafter.

The projected value of per capita water use is affected by the change in per capita annual income and the change in average family size during the period from the base year to the time to be forecasted, and also influenced by the initial value (NPCQ), which is the value of PCQ at the base year. The initial value NPCQ plays an important role in determining the projected value of PCQ, especially for a comparatively short-time forecasting. Equation 10.3 is a subsidiary part to Equation 10.2, because level equations are required to be given initial values, according to a principle of system dynamics.

There are two more equations directly related to residential water use, which are the adjustment equations for taking the factors of conservation policy and the coverage of the public water supply into consideration. They are:

AWREQ1.K=WREQ.K*(1-PCSM) (10.4)

and AWREQ2.K=AWREQ1.K/PWS.K (10.5)

in which:

AWREQ1: adjusted annual residential water use by the factor of conservation, in cubic metres.

AWREQ2: adjusted annual residential water use again by the factor of public water supply coverage, in cubic metres.

PCSM: fraction or percentage of water saved due to the effect of implementing the water conservation policy.

PWS: fraction of public water supply coverage in terms of population.

The first adjustment by the conservation factor assumes that a certain fraction or percentage of water will be saved because of the implementation of the water conservation policy. The fraction of water saved can be decided from literature, or from subjective assumption, which will be further discussed in the following section about parameter estimation.

The second adjustment is to reflect the situation where public water supply facilities do not serve the whole population in a city because of insufficient facilities and self-supply service. It is a very common phenomenon in Chinese cities that public water supply systems do not serve the whole urban population. When data obtained from a public water supply company is used, which covers a major part of the urban residential water use rather than the total, an adjustment to the residential water use is made by dividing them with the fraction of the population served by the company, to give an estimation of the total residential water use. However, only where the company serves a major fraction of the local urban residents, can this simple adjustment be valid. If the fraction of population served by the water supply company does not take a major part, less than fifty percent, for example, it may be insufficient to do such a simple adjustment. To know more about water use by residents who are not served by the public water company would become necessary.

The remaining level and rate equations in the residential subroutine are about the factors which affect residential water use or per capita water use, which give descriptions about the changing process of these factors during the forecast horizon. In order to make the model simple, and because the projected value of these factors are often adopted from other people's forecasts, no more exogenous factors, which may have some effect on the factors of concern, are taken into account. The changing process in each of these factors is simply treated as a single feedback loop, or the change in each of these factors is only explained by its own annual change rate, whether increase or decrease, rather than relating to any other variables. The annual change rate of each factor is actually the aggregate effect of the variables affecting it. However, the relationship between these factors of concern and some other variables are not given explicitly in this model. In other words, only the changing processes of these factors along the time dimension are clearly presented. The equations describing the change of (1) population, (2) per capita income, (3) family size, and (4) public water supply coverage are given as follows.

(1) population

POP.K=POP.J+DT*(RPIM.JK+RPIN.JK) (10.6)

RPIN.KL=POP.K*AVPR (10.7)

RPIM.KL=CPIM (10.8)

POP=NPOP (10.9)

where:

POP: numbers of urban population corresponding to the residential water use data, in persons.

RPIM: net numbers of immigrants from outside to the city's urban area during a year, which equals the numbers of immigrants minus the numbers of emigrants, in persons per year.

RPIN: net annual natural increase in urban population, which equals the numbers of birth minus the numbers of death, in persons per year.

CPIM: an assumed constant value of RPIM (net annual immigrants).

AVPR: net annual natural increase rate of the urban population, which equals birth rate minus death rate, as a fraction or in percentage.

NPOP: initial value of numbers of population.

The change of future population is dependent on the net natural increase rate, which equals the birth rate minus the death rate, and the net immigration rate, which equals the numbers of annual immigrants minus the annual emigrants. The annual net immigrants is assumed to be a constant because it often appears as a fixed number rather than a changing rate in social development plans. However, it may change with time. In practice, different numbers of annual net immigrants can be assumed for different periods by using the TABLE function which is built in the Professional DYNAMO, if information is available.

(2) per capita income

INC.K=INC.J+DT*RINC.JK (10.10)

RINC.KL=INC.K*AVIR (10.11)

INC=NINC (10.12)

in which:

INC: annual per capita income, in yuan per capita.

RINC: annual increase in per capita income, in yuan per capita per year.

AVIR: annual increase rate of per capita income, as a fraction or in percentage.

NINC: initial value of per capita annual income.

The change of per capita annual income is explained as a function of its annual increase rate, which is a fraction of the per capita annual income at the time of a simulation interval ahead, or a year before, due to the simulation interval is set as one year in this study. The value of annual increase rate can be a constant, or adopt different values for different periods in the horizon of forecasting.

(3) average family size

FAS.K=FAS.J+DT*RFAS.JK (10.13)

FAS.KL=FAS.K*AVFR (10.14)

FAS=NFAS (10.15)

in which:

FAS: the average numbers of people in a family, in people per family.

RFAS: annual change (increase or decrease) in family size, in people per family per year.

AVFR: annual change rate of family size, as a fraction or in percentage.

NFAS: initial value of family size.

Similar to the method used to deal with per capita annual income, the change of average family size is also simply treated as a function of its annual decrease rate. The annual decrease rate is assumed to be a fraction of the average family size at one year before. The value of the decrease rate can adopt a constant for the whole forecasting horizon or different values for different periods. The time-related values issued for one parameter can be put into the model by using the TABLE function.

(4) water supply coverage

$$PWS.K=PWS.J+DT*RPWS.JK \tag{10.16}$$

$$RPWS.KL=(1-PWS.K)*AVSR \tag{10.17}$$

$$PWS=NPWS \tag{10.18}$$

in which:

PWS: the fraction of population served by the public water supply company over the total urban population, as a fraction or in percentage.

RPWS: annual increase in the coverage of population served by public water service due to improvement of urban water supply facilities, as a fraction or in percentage.

AVSR: annual increase rate of public water supply coverage as a fraction of 1-PWS.K.

NPWS: initial value of the public water supply coverage.

The maximum public water supply coverage is one, or a hundred percent, so that the annual increase rate of water supply coverage is assumed to be a fraction of one minus the value of PWS at the time of one year ahead. It can also adopt a constant for the whole horizon of forecasting, or different values for different periods, according to the case being studied.

10.2.3 Parameter Estimation and Alternative Futures

In the residential water use subroutine, there are eight parameters and coefficients (see Table 10-1). They need to be determined, whether estimated or assumed, before the model is ready to be run. If there is any further disaggregation or sub-divisions, the numbers of parameters and coefficients will be multiplied. Estimating the values of these parameters, as discussed in Chapter Nine, is an important issue in the process of model building.

Table 10-1 Parameters in the Residential Subroutine

CPAI: coefficient between water use and per capita income.

CPAF: coefficient between water use and family size.

PCSM: an estimated fraction or percentage of water saved by implementing the water conservation policy.

CPIM: an assumed or estimated constant of numbers of annual net immigrants.

AVPR: net annual natural growth rate of urban population.

AVIR: annual increase rate of per capita income.

AVFR: annual change rate of family size.

AVSR: annual increase rate of public water supply coverage.

The values adopted for the parameters and coefficients are determined based on the local situation where it is being studied. In China, short-term and long-term socio-economic development plans are made for almost every city. From these plans, the parameters, such as CPIM, AVPR, AVIR, AVFR, AVSR, can be probably adopted; or at least, information about determining these parameters can be found in them. In addition, there are other available sources in China which can help to determine the value of these parameters, including industrial development plans, agricultural development plans, population increase control plans, etc. Different sources may produce different values for these parameters. These different values may be treated as alternatives.

The two coefficients CPAI and CPAF, and the parameter for water conservation PCSM, may not be directly obtained from anywhere, and therefore are estimated by the forecasters themselves. Similar research carried out by other researchers is an important reference source. The derived relationships from historical records by using single or multiple regression analysis is another way to estimate them. In China, a major problem in using regression analysis to determine the parameters is data availability, or the time-series is not long enough. However, the process of determining the coefficients and parameters is full of assumption-making, whether they are adopted from others, derived from historical analysis, or accepted with adjustments to either of these. Different values obtained from different assumptions may be treated as alternative values for model runs.

The number of alternative futures resulted from the forecast of residential water use depends on how many alternative values each parameter or coefficient has assumed or adopted. If each of the eight parameters and coefficients in the residential subroutine has two alternative values, for example, it can maximally result in two-hundred-and-fifty-six (2^8) alternative futures for residential water use. However, care must be taken in combining alternative values for the parameters and coefficients. Some combinations of the alternative values adopted for the parameters and coefficients may unlikely occur, or there are contradictions inside these combinations, although the alternative values are acceptable for individual parameters. If it is possible, each of the alternative futures resulted should be assessed as to whether or not it makes sense before it is accepted. Otherwise, results will be very misleading.

The alternative futures accepted can be shown in a bar-chart and a cumulative frequency curve, as the methods described in Section 9.5. A range, rather than a point value, of forecast can be obtained. From the probability distribution of the alternative scenarios, forecasts under certain probabilities can be derived. The discussion about alternative futures in the above is not only valid for residential water use, but for industrial, agricultural, and commercial water use as well.

10.3 INDUSTRIAL SUBROUTINE

One characteristic of industrial water use is the tremendous variation from one kind of industry to another, whether in terms of per unit productive value water use, or per employee water use, or per unit weight product water use. In addition, there are not as many factors considered in affecting industrial water use as those considered for residential water use (see the discussion in Chapter Five). In this study, according to the Chinese situation, industrial gross productive value is accepted as the factor affecting the demand for industrial water, and another two factors are related to the intensity of industrial water use, or per unit value water use. They are industrial water reuse rate, and the factor of technological improvement towards saving water.

10.3.1 Flow Diagram

Figure 10.2 presents the factors and the relationships between industrial water use and these factors, which are concerned in the model for forecasting industrial water demand.

10.3.2 Equations and Variables

The basic equation adopted for forecasting industrial water use is written as:

$$INDQ.K=APVQ1.K*INV.K \tag{10.19}$$

where:

INDQ: annual industrial water use, in cubic metres.

APVQ1: per unit gross industrial productive value water use, in cubic metres per ten-thousand yuan.

INV: annual gross industrial productive value, in ten-thousand yuan.

Industrial water use equals per unit productive value water use multiplied by total industrial productive value. It is the relationship employed in the per unit forecast method.

However, per unit value industrial water use is further related to some other factors. Firstly, it is assumed that there is an annual decrease rate, due to the improvement of industrial technologies towards saving water. And secondly it is adjusted by the change of industrial water reuse rate. The equations

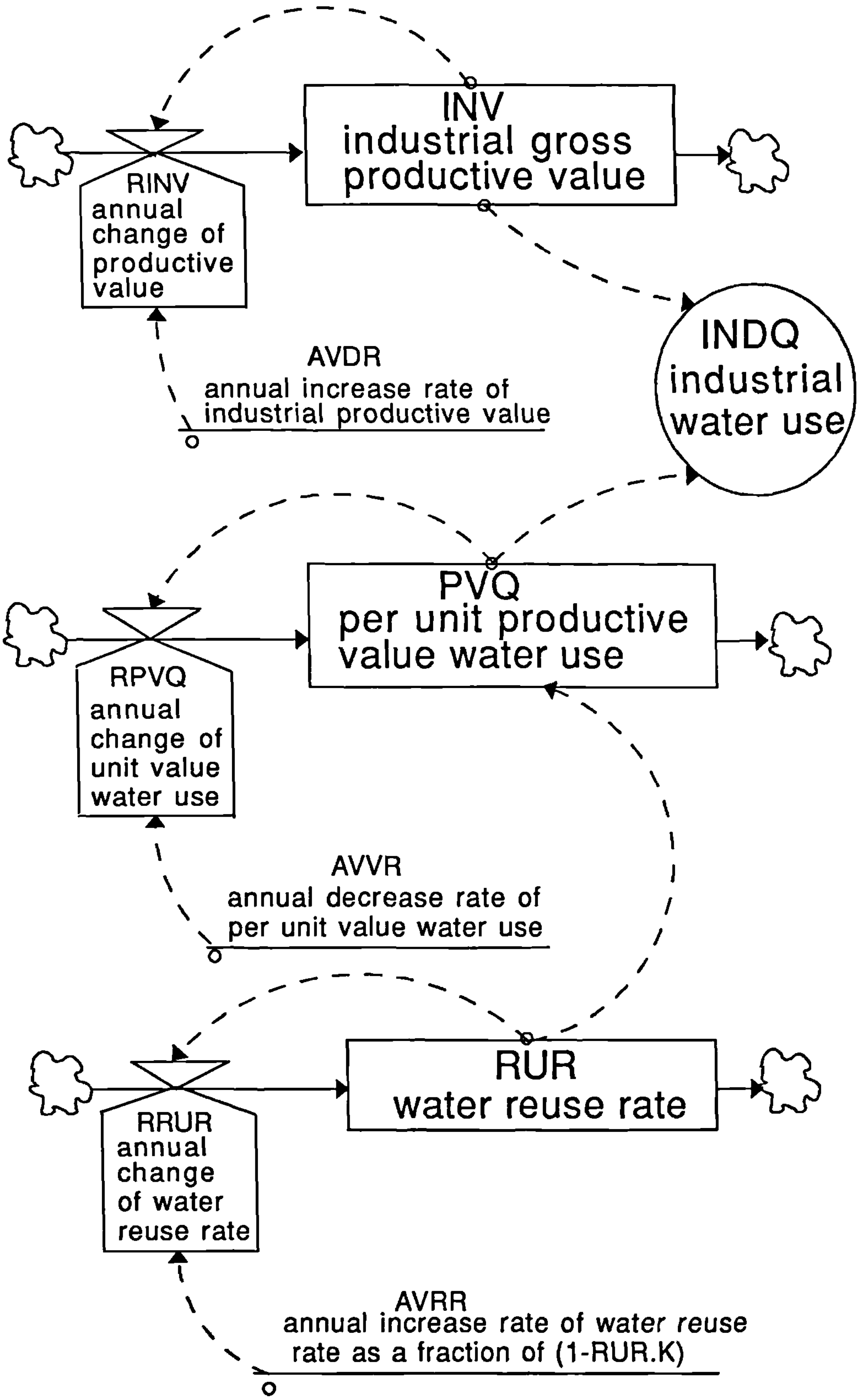


Figure 10.2 Flow Diagram of industrial water use

describing the change of per unit value water use caused by these two factors are presented as follows.

Taking technological improvement into account implicitly

$$PVQ.K=PVQ.J+DT*RPVQ.JK \quad (10.20)$$

$$RPVQ.KL=PVQ.K*AVVR \quad (10.21)$$

$$PVQ=NPVQ \quad (10.22)$$

in which:

PVQ: per unit productive value water use, before taking the factor of water reuse rate into account, in cubic metres per ten-thousand yuan.

RPVQ: annual decrease in per unit productive value water use owing to the improvement of technology, in cubic metres per ten-thousand yuan per year.

AVVR: annual decrease rate of per unit value industrial water use, as a fraction or in percentage.

NPVQ: initial value of per unit value industrial water use.

It is assumed that technological improvement will result in a continuous reduction in per unit value water use, particularly under the pressure of water shortage and water economization policy. The annual reduction of per unit value water use is assumed to be a fraction of the per unit value water use at the time of one year ahead. The value of the fraction adopted can be a constant lasting for the whole horizon of forecasting, or different values for different periods.

Adjustment by water reuse rate

$$APVQ1.K=PVQ.K*(1-RUR.K)/(1-NRUR) \quad (10.23)$$

where:

APVQ1 and PVQ: as defined previously. The relationship between them is given by the above equation: APVQ1 equals PVQ adjusted by the factor of water reuse rate.

RUR: water reuse rate, in percentage.

NRUR: the initial value of water reuse rate, in percentage.

The above equation (Equation 10.23) can be derived from Equation/Formula 5.5 that defines water reuse rate.

The exogenous variables which are explicitly included in the industrial subroutine are only: (1) gross annual industrial productive value, and (2) industrial water reuse rate. Their changing processes during the forecast horizon are described by the following equations.

(1) Industrial productive value

$$INV.K=INV.J+DT*RINV.JK \tag{10.24}$$

$$RINV.KL=INV.K*AVDR \tag{10.25}$$

$$INV=NINV \tag{10.26}$$

in which:

INV: annual industrial productive value, as defined before.

RINV: annual increase in gross industrial productive value, in ten-thousand yuan per year.

AVDR: annual increase rate of industrial productive value, as a fraction or in percentage.

NINV: initial value of annual industrial productive value, in ten-thousand yuan.

The change in industrial productive value is explained by its annual increase rate rather than relating to any other exogenous variables. Annual increase in industrial productive value is only a fraction of the productive value at one year ahead. The value of the fraction adopted can be a constant lasting for the whole horizon of forecasting, or different values for different periods, depending on the special case being studied.

(2) Water reuse rate

$$RUR.K=RUR.J+DT*RRUR.JK \tag{10.27}$$

$$RRUR.KL=(1-RUR.K)*AVRR \tag{10.28}$$

$$RUR=NRUR \tag{10.29}$$

where:

RUR: water reuse rate, as defined previously.
RRUR: annual increase in water reuse rate, in percentage.
AVRR: annual increase rate of water reuse rate as a fraction of 1-RUR.K.
NRUR: initial value of water reuse rate, as defined above.

Since the theoretical maximum value of water reuse rate is one or a hundred percent, the annual increase rate of water reuse rate is assumed to be a fraction of one minus the water reuse rate at the time of one year before. The annual increase rate (AVRR) can be a constant, or it can change with time as well.

10.3.3 Parameter Estimation and Alternative Futures

Without considering further disaggregation, there are only three parameters which need to be estimated in the industrial subroutine (see Table 10-2). However, if the industrial sector is further divided into two categories, the number of parameters will be doubled; and if it is divided into three categories, the number of parameters will be tripled; and so on.

Table 10-2 Parameters in the Industrial Subroutine

AVDR: annual increase rate of industrial productive value, as a fraction or in percentage.
AVRR: annual increase rate of water reuse rate as a fraction of 1-RUR.K.
AVVR: annual decrease rate of per unit value industrial water use, as a fraction or in percentage.

The value of AVDR can be obtained from urban industrial development plans, or economic development plans, which are available in most of Chinese cities. The value of AVRR, sometimes, is available from the official plans, where water economization has been paid much attention so that a target is often set for the industrial water reuse rate at some future time. The value of AVRR can also be determined by referring to the literature or from engineering analysis, because limitation for raising water reuse rate in different industries is an issue which is related to industrial techniques and engineering.

From historical records, there is a trend in which per unit industrial water use is decreasing. However when AVVR is estimated from historical analysis, attention should be paid to the fact that the decrease in per unit value water use that is reflected was caused by both technological improvement as well as the rise of water reuse rate. Here, AVVR only represents the effect of technological improvement, while water reuse rate is treated as a separate factor. Therefore, the effect of water reuse rate should be eliminated, if the value of AVVR is determined through analysing historical data. It is also helpful to use engineering analysis in determining the value of AVVR, if new technologies that will replace those currently used can be predicted.

Similar to the discussion on residential water use, alternative futures for industrial water use can be obtained by choosing alternative values for the parameters. The frequency distribution of the alternative forecasts comprises a picture that describes a range of industrial water use that is likely to occur, as well as the probability of an occurrence located at any part of the range.

10.4 AGRICULTURAL SUBROUTINE

Agricultural water use, although it is usually independent of the urban public water supply system, is considered as a part of the component of urban water use for the reason specified in Chapter Six. In this subroutine, the size of the area irrigated is chosen as the factor affecting the demand for agricultural water use. Three exogenous factors are related to the per unit area water use. They are canal efficiency, climatic factor, and the technology used in irrigation and soil water conservation.

10.4.1 Flow Diagram

The flow diagram shown in Figure 10.3 presents the factors concerned and their relationships with agricultural water use in the agricultural subroutine.

10.4.2 Equations and Variables

For agricultural water use, the basic equation in the forecasting model is:

$$AGRQ.K=APAQ1.K*IAR.K \tag{10.30}$$

where:

AGRQ: annual agricultural water use, in cubic metres.
APAQ1: annual per unit irrigated area water use, in cubic metres per mu.
IAR: size of the area irrigated, in mu (one mu is equal to one fifteenth ha.).

Total agricultural water use equals per unit area water use multiplied by the total irrigated area. This is the relationship employed in the per unit forecast method for the agricultural sector. Attention should be paid to APAQ1, which is defined as the annual per unit area water use, rather than per unit area water use for single cropping. When multiple cropping exists, water use for irrigating different crops within a year should be added together.

Per unit area water use is further related to three factors: (1) improvement in the technology of irrigation and soil water conservation towards reducing water use; (2) a rise in canal efficiency to reduce water loss during the water transfer process; and (3) the effect of climatic change from year to year. The relationships between per unit area water use and the three factors considered in the model are described by the following equations.

(1) Improvement in irrigation technology

$$PAQ.K=PAQ.J+DT*RPAQ.JK \tag{10.31}$$

$$RPAQ.KL=PAQ.K*AVATR \tag{10.32}$$

$$PAQ=NPAQ \tag{10.33}$$

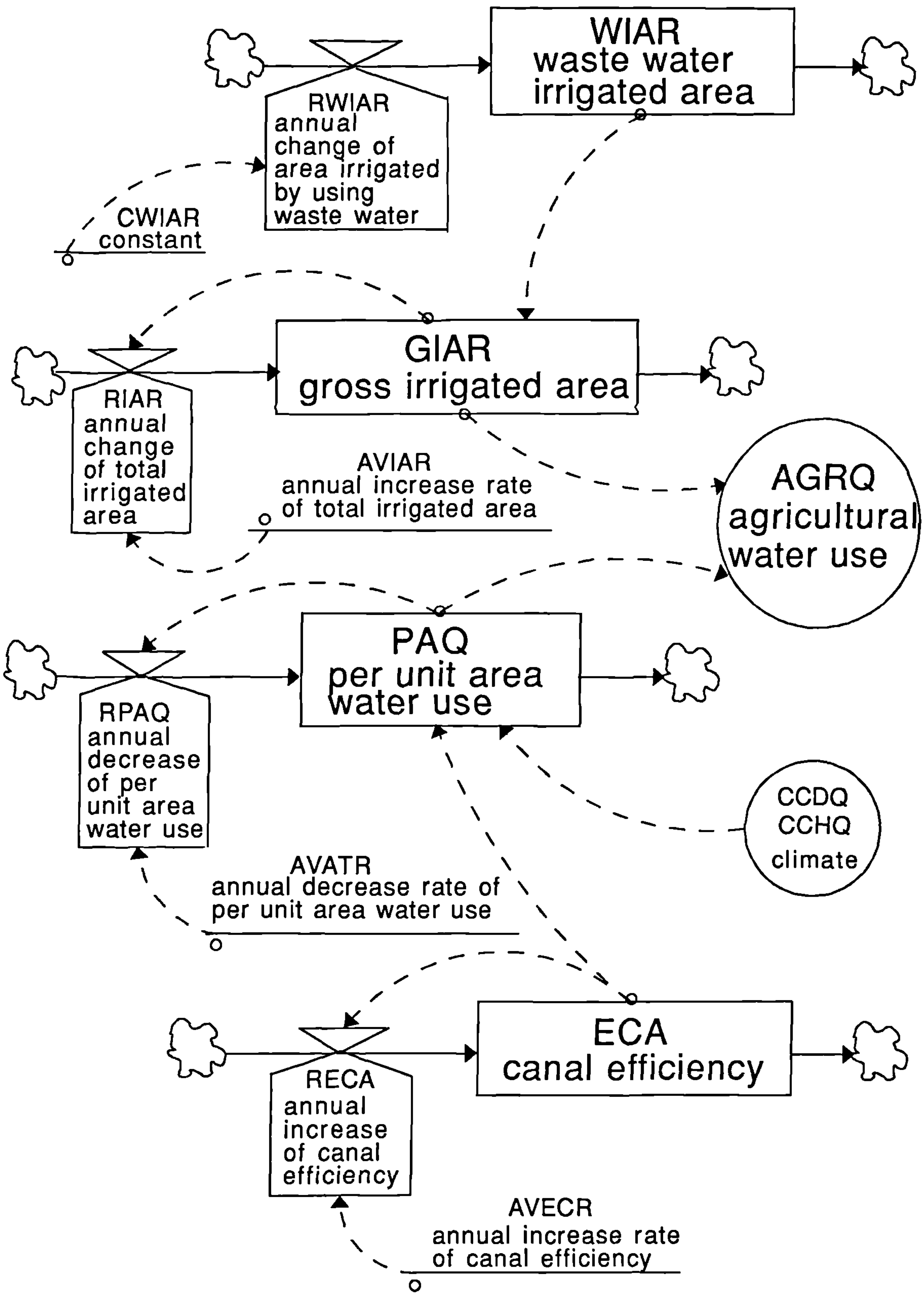


Figure 10.3 Flow Diagram of agricultural water use

in which:

PAQ: annual per unit area agricultural water use without considering the change in canal efficiency and climate, in cubic metres per mu.

RPAQ: annual decrease in per unit area water use because of the improvement in irrigation technology, in cubic metres per mu per year.

AVATR: annual decrease rate of per unit area water use, as a fraction.

NPAQ: initial value of per unit area water use.

The effect of improving irrigation technology, including irrigation method and soil water conservation technique, is taken into account implicitly. It is assumed that an annual decrease rate in per unit area water use will be produced, which can be a constant lasting for the whole horizon of forecasting, or different values for different periods.

(2) Raising canal efficiency

$$APAQ1.K=PAQ.K*NECA/ECA.K \qquad (10.34)$$

in which:

APAQ1 and PAQ: as defined previously. The relationship between them is stated in this equation, which APAQ1 equals PAQ adjusted by the change in canal efficiency.

ECA: canal efficiency, in percentage.

NECA: initial value of canal efficiency, in percentage.

According to the definition of canal efficiency given by Equation/Formula 6.3, the above equation can be derived. In fact, canal efficiency is an adjustment variable, which can be related to either the total or per unit area agricultural water use. In this study, it is related to per unit area water use, due to the distinction made between the factors affecting water demand and water use intensity. Agricultural water use employed in this study means the quantity of water drawn from the water source rather than the net amount of water which reaches the farm.

(3) Change in the climatic variable

$$DPAQ.K=APAQ1.K+CCDQ \quad (10.35)$$

$$HPAQ.K=APAQ1.K-CCHQ \quad (10.36)$$

in which:

DPAQ: annual per unit area water use in a dry year, in cubic metres per mu.

APAQ1: as defined above. To be parallel with DPAQ and HPAQ, it represents per unit area water use in a normal year.

HPAQ: annual per unit area water use in a humid year, cubic metres per mu.

CCDQ: a difference term of per unit area water use between a normal year and a dry year, in cubic metres per mu.

CCHQ: a difference term of per unit area water use between a normal year and a humid year, in cubic metres per mu.

For considering the influence of the climatic variable, based on the discussion in Section 6.3, only three typical hydrological years are concerned. They are normal year, dry year, and humid year. It is obvious that the change in per unit area water use caused by the change in climatic variable is a range rather than point values. However for simplicity and convenience, three point values were merely considered.

The remaining level and rate equations in the agricultural subroutine are about the factors, or exogenous variables, which affect agricultural water use or per unit area water use. They are: (1) the gross irrigated area, (2) waste water irrigated area, and (3) canal efficiency. The equations that describe the changing process of these factors during the forecast horizon are given as follows.

Gross irrigated area

$$GIAR.K=GIAR.J+DT*(RIAR.JK) \quad (10.37)$$

$$RIAR.KL=GIAR.K*AVIAR \quad (10.38)$$

$$GIAR=NIAR \quad (10.39)$$

where:

GIAR: total irrigated area, in mu.

RIAR: annual increase in the total irrigated area, in mu per year.

AVIAR: annual increase rate of irrigated area, as a fraction or in percentage.

NIAR: initial value of total irrigated area.

The gross irrigated area changes with an annual increase (or decrease) rate. Depending on the case studied, it may change with time or adopt a constant lasting for the whole horizon of forecasting.

Waste water irrigated area

$$WIAR.K=WIAR.J+DT*RWIAR.JK \qquad (10.40)$$

$$RWIAR.KL=CWIAR \qquad (10.41)$$

$$WIAR=NWIAR \qquad (10.42)$$

in which:

WIAR: size of the area irrigated by using urban waste water, in mu.

RWIAR: annual increase or decrease in the size of the area irrigated by using urban waste water, in mu per year.

CWIAR: an assumed constant value of RWIAR. It means that a constant value of annual increase or decrease in size of the area irrigated by using waste water is assumed for each of the coming years.

NWIAR: initial value of size of the area irrigated by using waste water.

The size of the area irrigated by using waste water is assumed to increase at a rate of a certain quantity per annum. With respect to the case studied, it can have different values for different periods, or a constant lasting for the whole horizon of forecasting.

There are three variables to represent the irrigated area: IAR, GIAR, and WIAR. The relationship among them is:

$$IAR.K=GIAR.K-WIAR.K \qquad (10.43)$$

The irrigated area of main concern in agricultural water use forecasting is the part irrigated by using fresh water (IAR), which equals the total or gross irrigated area minus the size of the area irrigated by using waste water.

Canal efficiency

$$ECA.K=ECA.J+DT*RECA.JK \quad (10.44)$$

$$RECA.KL=(1-ECA.K)*AVECR \quad (10.45)$$

$$ECA=NECA \quad (10.46)$$

in which:

ECA: canal efficiency, as defined previously.
RECA: annual increase in canal efficiency, in percentage.
AVECR: annual increase rate of canal efficiency as a fraction of 1-ECA.K.
NECA: initial value of canal efficiency.

Since the maximum value of ECA is one, or a hundred percent, the annual increase rate of canal efficiency is treated as a fraction of one minus the canal efficiency at the time one simulation interval ahead, or a year before, as the simulation interval adopted in this model is one year.

10.4.3 Parameter Estimation and Alternative Futures

In the agricultural subroutine, if there is no further disaggregation, there are six parameters which need to be estimated (see Table 10-3).

Table 10-3 Parameters in the Agricultural Subroutine

AVATR: annual decrease rate of per unit area water use, owing to improvement in the irrigation method, in fraction.

CCDQ: a difference term of per unit area water use between a normal year and a dry year, in cubic metres per mu.

CCHQ: a difference term of per unit area water use between a normal year and a humid year, in cubic metres per mu.

AVIAR: annual increase rate of irrigated area, as a fraction or in percentage.

CWIAR: an assumed constant value of RWIAR. It means that a fixed value is adopted for the annual change in size of the area irrigated by using waste water.

AVECR: annual increase rate of canal efficiency as a fraction of 1-ECA.K.

The values of AVIAR and CWIAR may be directly obtained from some official documents, such as agricultural development plans, urban economic development plans, etc. The value of CCDQ and CCHQ can be estimated according to literature or reports of local field research. In China, this kind of information can be obtained from local agricultural experimental stations. In the agricultural development plans, or some other relevant official documents, a numerical target for raising canal efficiency is often set for some future time based on engineering analysis, from which the value of AVECR can be decided.

When analysing the technological improvement in irrigation methods to determine the value of AVATR, attention should be paid to that reduction in per unit area water use is often associated with the reduction of water loss during water transfer process, or with the increase in canal efficiency. Since canal efficiency is another factor considered separately, the value of AVATR only reflects the change in per unit area water use which occurs within the farm-land. When it is said that a new irrigation method can save water by a certain amount or percentage, it usually refers to the comprehensive effect of reducing farm-land water use and raising canal efficiency. Thus, the effect of raising canal efficiency should be taken off in determining AVATR, when it is estimated from literature or engineering analysis.

Similar to residential and industrial water use, alternative futures of agricultural water use can be obtained by choosing alternative values for the parameters.

10.5 COMMERCIAL SUBROUTINE

There are some unsolved problems in forecasting commercial water use, such as restricted historical data, limited literature, and the unknown relationships between commercial water use and some major factors. These contribute many difficulties for building a model to be used for forecasting Chinese urban commercial water use. Under this condition, a simple aggregated forecast model is built up, in which only two factors, urban population and per capita annual income, are considered.

10.5.1 Flow Diagram

The relationships between commercial water use and the two factors concerned in the forecast model are shown in Figure 10.4.

10.5.2 Equations and Variables

The basic equation in the commercial subroutine has the same form as that adopted in the residential subroutine.

$$COMQ.K=PCMQ.K*POP.K*365/1000 \tag{10.47}$$

where:

COMQ: annual commercial water use, in cubic metres.
PCMQ: per capita daily commercial water use, in litres per capita per day.
POP: number of urban population, in persons.

Annual commercial water use equals per capita daily commercial water use multiplied by the number of urban population and the number of days in a year, divided by a thousand (one thousand is the factor of conversion from litres to cubic metres).

Per capita commercial water use is further related to per capita annual income and urban population. The role of population here is different from the role of population in residential water use. In the commercial sector, population does not only influence the demand for water but the intensity of commercial water use as well. The form of function adopted for determining per capita commercial water use is also different from that adopted in residential water use. The following exponential function is used.

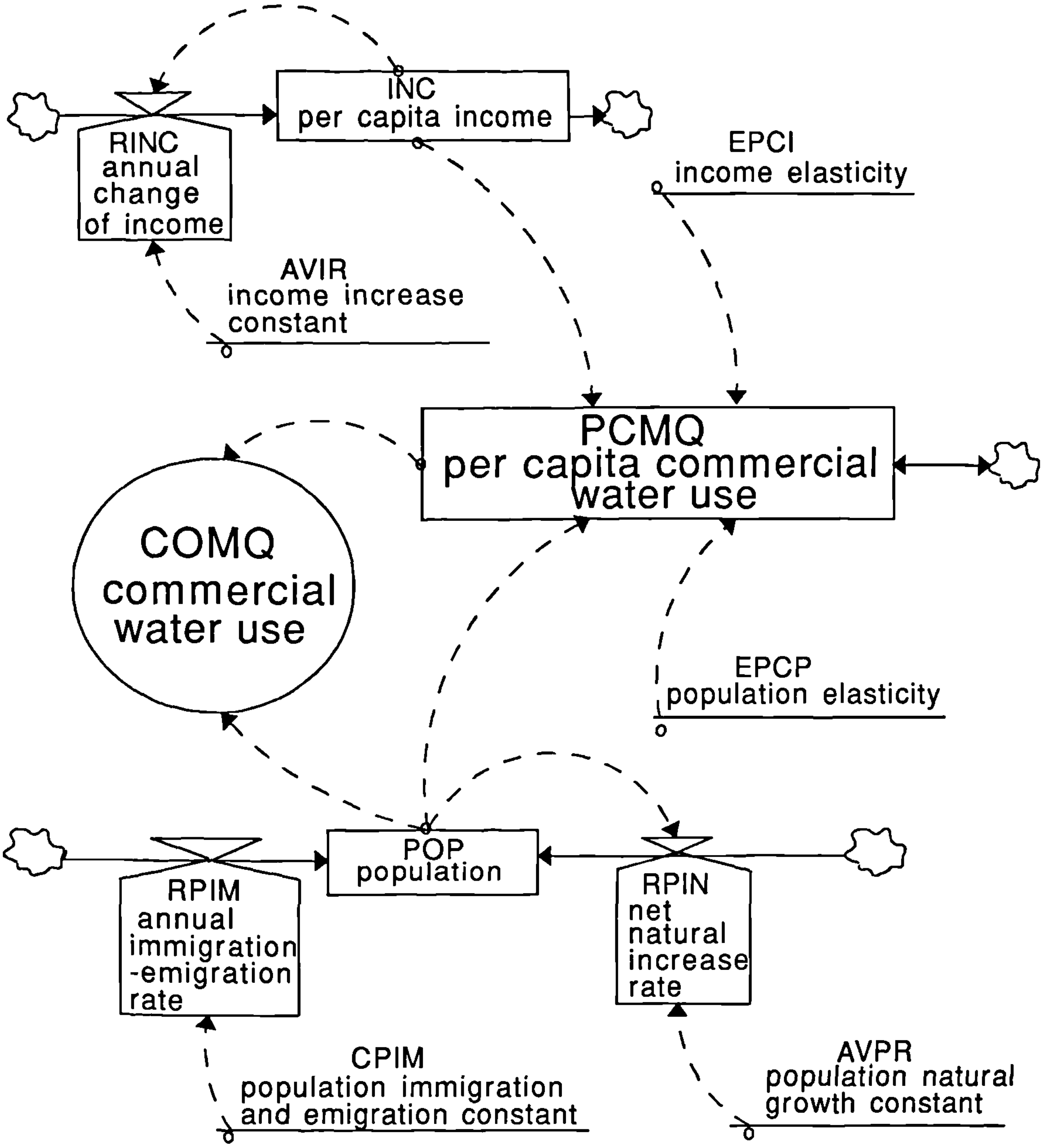


Figure 10.4 Flow Diagram of commercial water use

PCMQ.K=NPCMQ*(POP.K/NPOP)**EPCP*(INC.K/NINC)**EPCI (10.48)

in which:

PCMQ: per capita commercial water use as defined above.
NPCMQ: the initial value of PCMQ.
POP: population as defined above.
NPOP: initial value of POP.
INC: per capita annual income, in yuan.
NINC: initial value of INC.
EPCP: population elasticity of per capita commercial water use.
EPCI: income elasticity of per capita commercial water use.
**: exponential function.

The change in per capita commercial water use depends on the change in urban population, and the change in per capita annual income.

The form of function accepted here is originated from Equation 9.20. When both linear and logarithm form relationships exist, theoretically, whether a linear equation like Equation 10.2, or an exponential equation like Equation 10.48, should not cause much difference in the result of forecasts. One advantage of choosing exponential equation is that the elasticities derived from logarithmic regression analysis can be taken into account. The choice made here is more intended to present an alternative than saying that this form is superior.

The two factors or exogenous variables concerned in this subroutine: urban population and per capita annual income have been employed in the residential subroutine. The equations and variables describing the change in them are exactly the same as those described in the residential subroutine. It is unnecessary to repeat here.

10.5.3 Parameter Estimation and Alternative Futures

The parameters needed to be estimated in the commercial subroutine are listed in Table 10.4. Except for the repeated parameters that have appeared in the residential subroutine, there are only two elasticities required to be determined.

Table 10-4 Parameters in the Commercial Subroutine

EPCP: population elasticity of per capita commercial water use.
EPCI: income elasticity of per capita commercial water use.
CPIM: an assumed or estimated fixed value of annual net immigrants.
AVPR: net annual natural increase rate of urban population.
AVIR: annual increase rate of per capita income.

They are the population elasticity EPCP and income elasticity EPCI in terms of commercial water use. For estimating the values of the two elasticities, historical regression analysis is a commonly used method, and researches carried out in the literature can be referred.

Alternative futures of commercial water use can be constituted from different combinations of the parameters when alternative values are adopted for them.

10.6 INITIAL VALUES

Except for the variables and parameters, another component in the subroutines are the initial values. According to a principle of system dynamics, all the level variables are required to be given an initial value. Therefore, the number of initial values equals the number of level equations in the simulation model. All the initial values required in the simulation model, including the four subroutines, are listed in Table 10-5. If further disaggregation is involved, there will be more than those listed.

In terms of water use study, the initial values give the information about water use and the relevant factors at current or recent stage; or they give answers to the first question in the conceptual model as described in Section 9.1, as well as information about the current situation of the factors or exogenous variables considered.

Table 10-5 Initial Variables in the Simulation Model

In the residential subroutine:

NPCQ: initial value of per capita daily water use.
NPOP: initial value of number of population.
NINC: initial value of per capita annual income.
NFAS: initial value of family size.
NPWS: initial value of the public water supply coverage.
NTIME: initial value of TIME when the simulation is wanted to be started.

In the industrial subroutine:

NPVQ: initial value of per unit value industrial water use.
NINV: initial value of annual industrial productive value.
NRUR: initial value of water reuse rate.
NTIME: initial value of TIME when the simulation is wanted to be started.

In the agricultural subroutine:

NPAQ: initial value of per unit area water use.
NIAR: initial value of total irrigated area.
NWIAR: initial value of size of the area irrigated using waste water.
NECA: initial value of canal efficiency.
NTIME: initial value of TIME when the simulation is wanted to be started.

In the commercial subroutine:

NPCMQ: the initial value of PCMQ.
NPOP: initial value of number of population.
NINC: initial value of per capita annual income.
NTIME: initial value of TIME when the simulation is wanted to be started.

Before deciding which one of the recent years should be chosen as the base year, or whether the recorded values of the level variables in that year are accepted as the initial values, consideration should be given to the following aspects.

Firstly, the year chosen should represent a 'normal' year i.e. no unusual event happened in that year, including natural damage such as flood, serious drought and earthquake; and man-made events such as war; or any other event that has effect on water use and seems quite unusual to the local situation. Sometimes, in order to avoid bias, the average values of several continuous years can be used instead of the values in a single year. For obtaining the average, if an even number of years is chosen, for example two or four years, it will cause a little problem in determining the value of NTIME; if too many years are put together, it will fail to reflect the 'current or recent' situation as another condition required. So, the average values in three continuous years would be a better choice.

Secondly, all the initial values required should be available in the year chosen. This is a very basic condition. Otherwise, it would be impossible to run the model.

And thirdly, try to choose the year as recent as possible. An assumption made in building the forecasting model is that future water demand is more related to current water use than to past water use. The larger the distance between the base year and the year projected, the less reliable is the resultant forecast.

Therefore, when the model is applied in practice, a criterion for selecting the base year is: data needed to be collected for that year is available, representative, and as current as possible.

When there are difficulties in choosing a representative base year, a few sets of initial values may be adopted as alternatives. The results of water use forecasts which result from different sets of initial values can be treated as 'alternative futures' of forecast.

10.7 STRATEGIES FOR USING THE SYSTEM DYNAMIC MODEL

The model described above is a very general one, in terms of its model structure, variables concerned, undecided parameters, etc. When it is used in practice, there are certain flexibilities in determining the structure, variables of concern, and the values attributed to the parameters. The following strategies are suggested for dealing with these issues.

Firstly, within each subroutine or sector, further divisions are possible. The level of further disaggregation is greatly dependant on data availability and the inner-structure or constitution of the water use sector, which is much related to the special case being studied. In the case study presented in the next chapter, for example, industrial water use is further divided into four sub-sectors, due to the unbalanced industrial structure that exists in the city analysed. In order to make the structure of the model clear and to prevent any misleading impact because of adopting further disaggregation, the model has been simply described. The method of forecasting used to deal with further divided sub-sectors is similar to that used for the aggregate sector, although different values might be given to the initial variables and parameters.

Secondly, in terms of the variables concerned, for any particular Chinese city which are restricted by data availability or any other special local situation, different proxies of the factor that influences the demand for water may be adopted. For example, under some conditions, numbers of industrial employees may be used instead of the industrial productive value in the industrial subroutine, and numbers of commercial employees may be used instead of urban population in the commercial subroutine, etc. On the other hand, more exogenous variables that influence the intensity of water use, or per unit water use, may be combined into the model, if relationships between water use and these variables are proven to exist.

However, different proxies of one factor are not allowed to appear simultaneously in the forecasting model, in order to avoid double counting of the effect of the same factor. For example, both per capita annual income and per capita annual expenditure can be used to represent the level of living standard and they must be closely related to each other, so that it is improper to combine both of them into the simulation model.

When extra or more variables are considered to combine into the simulation model, there are generally two approaches which can be followed. One is to relate them with the per unit water use by finding out the coefficients or elasticities; another is to treat them as adjustment factors by estimating their effects on water use without introducing them into the model explicitly.

Thirdly, the adoption of values for parameters, coefficients, and elasticities basically follows the principle of 'respecting the special case being studied', although literature and engineering analysis are very useful for determining some of them. Except for the reason declared in Section 9.1, it is also believed that better understanding of the local situation about water use will result in more reliable forecasts.

And finally, for determining and modifying the coefficients and elasticities, or evaluating the performance of the model, historical validation can be used. Using the model that has been built, not only water demand in the future but water demand in the past can be projected. Comparing the projected with the historical records, it can be assessed whether or not the model produces accurate forecasts. Except for the coefficients and elasticities that are uncertain, all the other parameters are determined in forecasting past water demand. If the model does not produce accurate forecasts, through the procedure of trail and error, the values attributed to the coefficients and elasticities may be adjusted until acceptable forecasts are produced. If the model produces accurate forecasts, it may be used as a proof of its reliability.

However, when using historical records to prove the reliability of a forecast model, the question of whether or not the pattern or relationship which existed in the past will continue in a long-term future arises. It falls into the dilemma of whether or not to adjust the coefficients of a measurement model when it is used in forecasting, again.

10.8 SUMMARY

In this chapter, a computer simulation model using the system dynamic approach is presented. The model is composed of four subroutines as described in Section 10.2-10.5. In each subroutine, a flow diagram showing the components and the relationships concerned in the model is placed at the beginning; then, the major part of the model: equations and variables combined into equations are presented and explained; and thirdly, the parameters and coefficients which are needed to be issued values are recognized from the equations, and suggestions about how to estimate these parameters and where to find the relevant information about them are discussed. There is an obvious relationship between the alternative values adopted for the parameters and the alternative futures of forecast. *The level variables in the subroutines are* required to have their initial values. For deciding the initial values, or a base year selection, it should be followed that the values which need to be obtained are available, representative, and as current as possible. When there are alternative sets of initial values, they can also make a contribution to the alternative futures of forecasts.

The simulation model described is not only intended to present a simple model but to provide a method or a way of thinking for dealing with the problem of long-term urban water use forecasting in general. The strategies for using the model, which are described in the last section, are intended to assist its application in practice.

Chapter Eleven
TAKING LANZHOU URBAN AREA AS A CASE STUDY

11.1 INTRODUCTION

Lanzhou is the capital city of Gansu province. It consists of five districts (Chengguan, Xigu, Qilihe, Anning, and Honggu), and three rural counties (Yuzhong, Yongdeng, and Gaolan), in which the first four of the five districts constitute the city's urban area (shiqu) (see Figure 11.1). The fifth district, mainly a coal mining area, is located about eighty kilometres west of the urban centre. Due to the spatial distribution, Lanzhou Water Company is only responsible to supply water to the four urban districts. The mining district and the town centres of the counties have their own independent water supply sources and facilities. Since this study is generally based on the water company's historical records, the boundary of the study area is drawn to include only the four urban districts; that is to say, the following water demand forecasting is for the urban area (shiqu) only, rather than for the whole city of Lanzhou.

Lanzhou Water Company supplies water to residential, industrial, and commercial water users located within the four urban districts. Water used for agricultural purposes is directly drawn or diverted from the Yellow River by farmers themselves. Self water supply by enterprises is not very common, only accounting for less than 10 percent of the total. In terms of water supply capacity, surface water takes about 75 percent of the total, and ground water constitutes another 25 percent. Surface water is drawn from the Yellow River at its upper site, or the western end of the urban area. A major part of the surface water drawn is supplied to the thermoelectric and chemical industries located

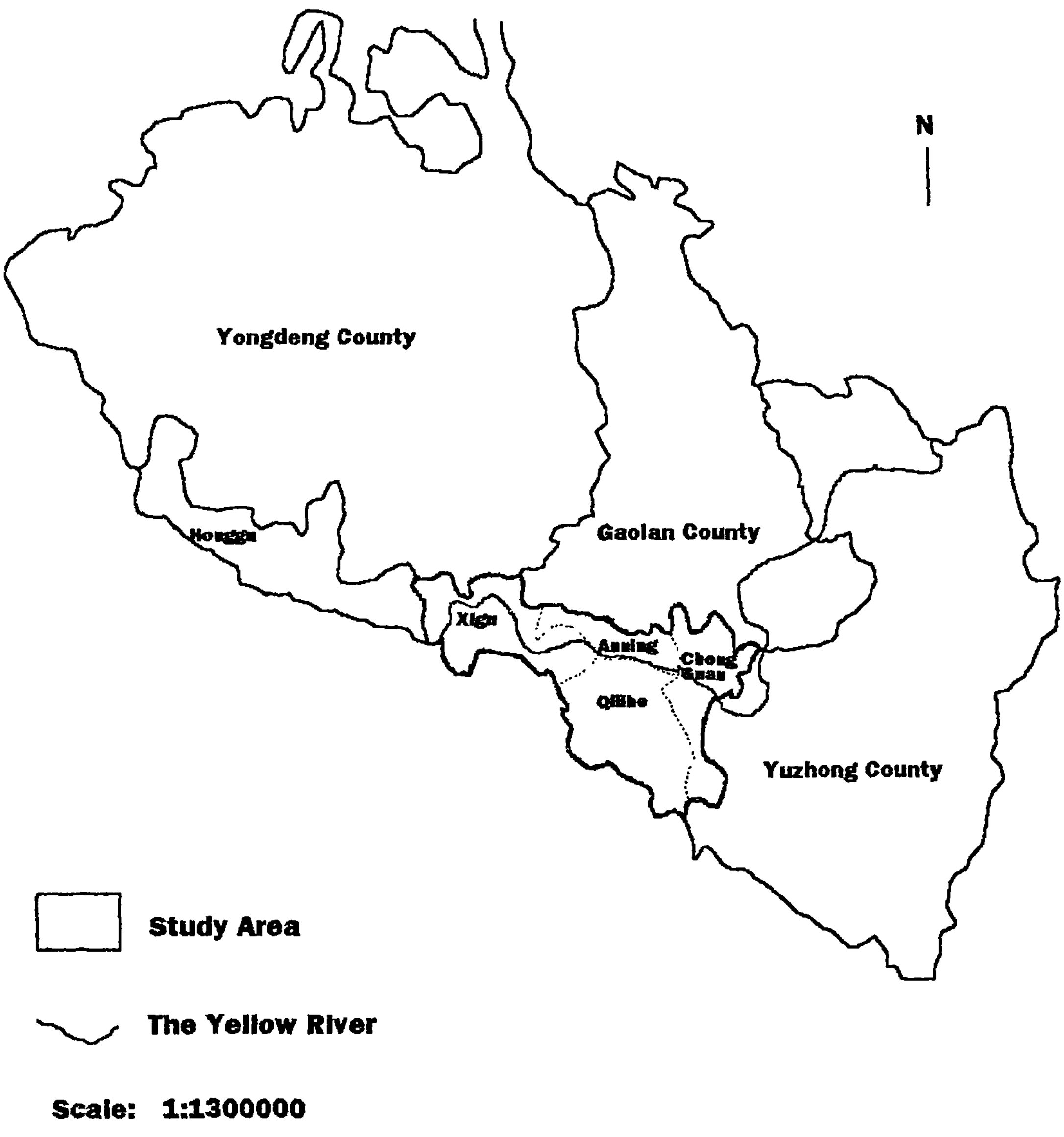


Figure 11.1 Map of Lanzhou City

in the west district (Xigu). The urban population of Lanzhou and their activities (Shiqu) are intensively concentrated within a long narrow belt consisting of two small basins along the Yellow River, with a length of 40 kilometres and a width of less than 1 kilometre at the narrowest part. Except for Xigu District, the other three districts are located in the eastern basin. The distance from the centre of eastern basin to the surface water source is over thirty kilometres, so that the three districts in the eastern basin are mainly depending on ground water.

Similar to many other Chinese cities, Lanzhou is facing the problem of water shortage in its eastern districts, Chengguan District in particular. The major reason is insufficient water resources, according to an officer of Lanzhou Water Company, who was interviewed by this author. For example, the amount of water actually drawn from two of its ground water sources operated by the company in 1992 only reached 70 per cent of their designed capacity, since the depletion of the ground water resources. Meanwhile, poor water supply facilities in some parts of the urban area is another reason for the insufficient supply of water in those areas. About 107 thousand people, forming 8 per cent of the total urban population, was reported to face insufficient water service due to poor or insufficient water supply facilities in 1988 (LWC, 1989). In order to improve the water supply service in the eastern districts, a water transferring project, which diverts water from the western surface water source to the eastern districts, was built in 1986, and expanded again in 1992. However, the problem of water shortage has not been completely resolved.

Under the above situations, and for the consideration of supplying enough water to meet the increasing future demands, investment in building new water supply facilities in Lanzhou urban area is necessary. On the other hand, Lanzhou is the largest city located in the upper reaches of the Yellow River. It consumes a huge amount of water directly or indirectly drawn from the river. Conflicts in water use among the upper, middle, and lower reaches within the

Yellow River catchment is becoming increasingly more serious. A project of a whole valley-wide water resources planning for rational utilization and regional distribution of water resources along the Yellow River is underway. However, before making any decision about the allocation of water resources along the river, investigation should be made about how much water will be demanded by different areas in the future, especially water demand by large cities which consume water intensively. A reliable long-term urban water demand forecast for Lanzhou is beneficial to the issue of water resources management in terms of the city and the whole river valley. Thus, using the model described in Chapter 10, long-term urban water demand in Lanzhou urban area by sectors i.e. residential, industrial, agricultural, and commercial, are forecasted.

11.2 FORECASTING THE RESIDENTIAL WATER DEMAND

Residential water use currently takes about 20 percent of the total water supplied by Lanzhou Water Company. In terms of the method in which water is supplied to households, there are three types of services that are in operation: household-tap, compound-tap, and neighbourhood-water-station. The neighbourhood-water-station is the oldest method of public water supply, and is being gradually replaced by the other two methods. According to the water company, by the end of 1988, there were 75 water-stations in operation (LWC, 1989). Household water taps have been installed in almost all apartment buildings. However, in areas occupied by traditional Chinese single-storey houses, where people used to live on station-water, compound-tap water is becoming common. Up to the end of 1988, 2,500 compounds, which covered about ten thousand families, had been improved, from using station-water to compound-tap supply (LWC, 1989). It has been reported that certain differences in per capita daily water use exist between the people who use station-water or compound-tap water, and people who are served by household-tap water. An investigation carried out in Beijing in early 1980s revealed that per capita water use in apartment buildings double that in the single-storey houses (Yang, Ren, et al., 1984, p54).

Since the dissimilarity in water availability from the west to the eastern part of Lanzhou city, there are clear variations in per capita water use from the western district to the eastern districts. Taking 1990 for example, per capita daily water use was 192 litres in the Xigu District, compared with 124 litres in the eastern three districts on average (LWC, 1990).

However, unavailability of data restricts further disaggregations in residential water demand forecasting. Otherwise, the factor of house type might be taken into account; and the forecast might even disaggregate to district scale rather than the whole urban area in aggregate. The difficulty mainly comes from the projected values of future population, level of income, and even the current status of income of people who live in different type of houses. There are no available statistics based on the classification of house type; and in the available studies on Lanzhou's future, population and income level are not projected on a district basis, nor in terms of house type. If further research is carried out, by putting great effort, these difficulties may possibly be overcome. However it has been impossible to do this for this thesis by this author herself.

Therefore, although further disaggregation might be desirable, the aggregated simulation model described in Section 10.2 is adopted, without any particular adjustment for the special case being studied.

11.2.1 Determining Initial Values and Parameters

11.2.1.1 Determining the initial values

Determining initial values, put simply, requires the selection of a year, or a base year as it is often called, in which all the values of the initial variables are available. So, NTIME is the first initial variable needed to be decided. According to the three criteria of base year selection described in Section 10.6, the base year should be as recent as possible. However, in this case study, NTIME is decided to be 1986, not only because the data in this year is available and representative, but for the purpose of testing the model as well. By contrasting what is projected by running the model with historical records during 1987-1990, a process of trial and error may be necessary for determining the value of some parameters. Although it is not very reliable to judge a long-term model from a short-term performance, it helps to improve the performance of the model at the very beginning. For the same basic reason, 1986 is set for all the NTIMEs in the other three subroutines.

As listed in Table 10-5, as well as for NTIME, there are five initial variables in the residential subroutine. The value of NPCQ and NPOP are obtained from the water company's statistics. There is a difference between the number of population supplied water by the company and the total population in the urban area. In order to make the data on population correspond to the data on water use, the number of population served by the water company is adopted. The total residential water use in the whole urban area is derived by dividing the percentage of population covered by the public water supply. The number of NINC and NFAS are obtained from the Lanzhou City Statistical Year-book, which are calculated from sample data rather than as the population. The number of NPWS is the quotient of the population served by the water company divided by the total urban population.

In order to avoid any bias caused by the choice of base year, another set of initial values, which are the 1985-87 three-year's average, is accepted as an alternative, whereby the NTIME is also set as 1986.

Table 11-1 Initial Values Accepted in the Residential Subroutine

Initial Variables	Alternative Values Adopted	
	Alternative 1	**Alternative 2**
NPCQ	137	132.4
NPOP	981363	993613
NINC	942	872.2
NFAS	3.73	3.76
NPWS	0.80	0.80
NTIME	1986	1986 (85-87 average)

11.2.1.2 Determining the parameters

The eight parameters listed in Table 10-1 are needed to give values before forecasting residential water demand by running the simulation model. The determination of the values of CPAI and CPAF is related to the analyses carried out in Section 4.3 and Section 4.5. Three alternative values are adopted for each of them. For CPAI, one value (0.0127) is derived from Equation 4.4 (dividing 0.00093 by the price of water 0.2 yuan/cubic metre, and then multiplying the quotient by 1000 and dividing by 365); the value (0.0028) is directly from Equation 4.8; and another value (0.0191) is the average of the slopes of Equation 4.6, 4.8, and 4.10. Since this is a city-scale forecast, the slope obtained from the city-scale analysis is accepted. The nation-scale analysis has been recognized as greatly obscuring the effects of other factors, due to the method of data classification, as discussed in Section 4.3.5. Thus, the slope obtained from the national analysis is accepted as an alternative. The average value of the slopes obtained from the inter-city, city, and household-scale analysis is treated as another alternative. For CPAF, the slopes in Equation 4.13, 4.14 and 4.15, are accepted as three alternative values.

The values of AVPR and CPIM, which are related to urban population growth, are adopted from the "Lanzhou City Developmental Plan - A study" (referred as LCDP hereafter) (CA-GI, 1992). In the LCDP, three alternative values: low, middle, and high, are assumed for each of the two parameters. Nevertheless only three combinations: low-low, middle-middle, and high-high, rather than nine as it can be maximally combined, are to be forecasted. In order to reduce the complexity or the number of alternative futures, the low-low, middle-middle, and high-high, combinations will be adopted in this case study. That is the reason why they are emphasised in italics in Table 11-2.

Parameter AVIR, the annual increase rate of per capita income, was not given in the LCDP. According to the increase rate from 1981 to 1989 in Lanzhou, and referring to the developmental target set for other Chinese cities (Xu Deqian, 1992b), two alternatives are adopted for it. One is a constant for the whole horizon of forecast; another is a series of values changing with the change of TIME, using a TABLE function (see Table 11-2).

There is no available source for AVFR and AVSR. Referring to the historical changes in average family size and public water supply coverage during the 1980s, and analysing the decreasing limit for family size, and increasing public water supply coverage in terms of Lanzhou's situation, a series of values is accepted for each of them, which are different values with the change in FAS or PWS (see Table 11-2). No alternative values are adopted for these.

The value of PCSM is decided based on some general knowledge about the current water conservation movement in China. A value of 0.025 is simply assumed for it from a long-term perspective. In other words, 2.5 percent of residential water use is assumed to be saved because of the continuous implementation of the water economization policy. No alternative is adopted (see Table 11-2).

Table 11-2 Values Adopted for the Parameters in the Residential Subroutine

Parameters	Alternative Values Adopted		
	Alternative 1	**Alternative 2**	**Alternative 3**
1. CPAI	0.0127	0.0191	0.0028
2. CPAF	-5.6	-4.1	-4.5
3. PCSM	0.025		
4. CPIM	*14000*	*20000*	*6500*
5. AVPR	*0.012*	*0.0137*	*0.011*
6. AVIR	0.05	(TIME:1986-2026, 10)* 0.06/0.05/0.04/0.03/0.02	
7. AVFR	(FAS:3.8-2.8, -0.2) -0.026/-0.02/-0.02/-0.015/-0.01/-0.005-		
8. AVSR	(PWS:0.8-1.0, 0.05) 0.05/0.03/0.03/0.01/0		

Note: Using the TABLE function, an arbitrary relationship between one variable and another variable can be expressed. Here, the independent variable is TIME. Its range is from year 1986 to year 2026. Dividing the range into equal segments, which equals to 10 for this case, the corresponding values of the dependent variable (AVIR) are given as listed. For example, when TIME is 1986, the value of AVIR is 0.06; when TIME is 1996, the value of AVIR is 0.05, and so on. The followed expressions that have the same form are identical in the explanation. (Details refer to Pugh-Roberts Associates, 1986, p5-7 to p5-13)

11.2.2 The Simulation Model

The following computerized simulation model is presented in order to give a complete description of the system dynamic simulation model used for forecasting residential water use. Combining it with the Professional DYNAMO, it is ready to be run. In terms of the values of parameters and initial values given, it is only one of the alternative futures that is resulted from running the model.

RESIDENTIAL WATER USE FORECASTING

```
L PCQ.K=PCQ.J+DT*(CPAI*RINC.JK+CPAF*RFAS.JK)
NOTE PER CAPITA DAILY WATER USE (litres/capita/day)
P CPAI=0.0127
P CPAF=-5.6
N PCQ=NPCQ
C NPCQ=137
L INC.K=INC.J+DT*RINC.JK
NOTE PER CAPITA ANNUAL INCOME (yuan/capita)
R RINC.KL=INC.K*AVIR.K
A AVIR.K=TABLE(TAVIR,TIME.K,1986,2026,10)
T TAVIR=0.06/0.05/0.04/0.03/0.02
N INC=NINC
C NINC=942
L FAS.K=FAS.J+DT*RFAS.JK
NOTE AVERAGE FAMILY SIZE (persons/family)
R RFAS.KL=FAS.K*AVFR.K
A AVFR.K=TABLE(TAVFR,FAS.K,3.8,2.8,-0.2)
T TAVFR=-0.026/-0.02/-0.015/-0.01/-0.005/0
N FAS=NFAS
C NFAS=3.73
A WREQ.K=PCQ.K*POP.K*365/1000
NOTE ANNUAL RESIDENTIAL WATER USE (cubic metres)
N POP=NPOP
C NPOP=981363
L POP.K=POP.J+DT*(RPIM.JK+RPIN.JK)
NOTE NUMBER OF POPULATION (persons)
R RPIN.KL=POP.K*AVPR
P AVPR=0.012
R RPIM.KL=CPIM
C CPIM=14000
A AWREQ1.K=WREQ.K*(1-PCSM)
NOTE RESIDENTIAL WATER USE ADJUSTED BY CONSERVATION
A PCQ1.K=PCQ.K*(1-PCSM)
NOTE PER CAPITA WATER USE ADJUSTED BY CONSERVATION
P PCSM=0.025
A AWREQ2.K=AWREQ1.K/PWS.K
NOTE RESIDENTIAL WATER USE ADJUSTED BY PUBLIC WATER SUPPLY
          COVERAGE
L PWS.K=PWS.J+DT*RPWS.JK
NOTE WATER SUPPLY COVERAGE IN POPULATION (fraction)
N PWS=NPWS
C NPWS=0.80
R RPWS.KL=(1-PWS.K)*AVSR.K
A AVSR.K=TABLE(TAVSR,PWS.K,0.8,1.0,0.05)
T TAVSR=0.05/0.03/0.03/0.01/0
N TIME=1986
SPEC DT=1/LENGTH=2020/SAVPER=1
RUN
```

11.2.3 The Result of Forecast

Using the simulation model presented in the above section, adopting different combinations of the alternative values of the parameters and initial values given in Table 11-1 and Table 11-2, one hundred and eight forecasts of residential water use were obtained for each coming year. Table C-1 in Appendix C gives the forecasts of total annual residential water use and per capita daily water use projected for years 2000, 2010 and 2020. The number of alternative combinations can be calculated from "$\underline{2}$*3*3*1*$\underline{3}$*2*1*1=108", in which the underlined "2" is the number of sets of initial values; the underlined "3" is the number of combinations of CPIM and AVPR as explained in Section 11.2.1.2; and the others are the number of alternative values adopted for each of the other six parameters. The simulation model was run once for each of the alternative combinations. The one hundred and eight results obtained were analysed statistically. Taking years 2000, 2010 and 2020, the statistics for residential water use in the three years are shown in Table 11-3. The frequency distribution of predicted residential water use in years 2000, 2010 and 2020, are presented in histograms in Figure 11.2, Figure 11.3 and Figure 11.4 respectively.

Table 11-3 Statistics of Forecasted Residential Water Use (in 10^4 m^3)

For-Year	Mean	Std err	S.E/Mean	Std dev	Skewness	Range
2000	8283.07	69.67	0.008	724.01	0.056	2681
2010	10711.69	145.92	0.014	1516.42	0.137	5559
2020	14091.32	269.03	0.019	2795.81	0.274	10812

11.3 FORECASTING THE INDUSTRIAL WATER DEMAND

Industrial water use in Lanzhou urban area is unevenly distributed among industries, due to the unbalanced industrial structure and the tremendous variation of water requirement from one industry to another. Chemical and petrol industries are the two major industries within the area studied. They take

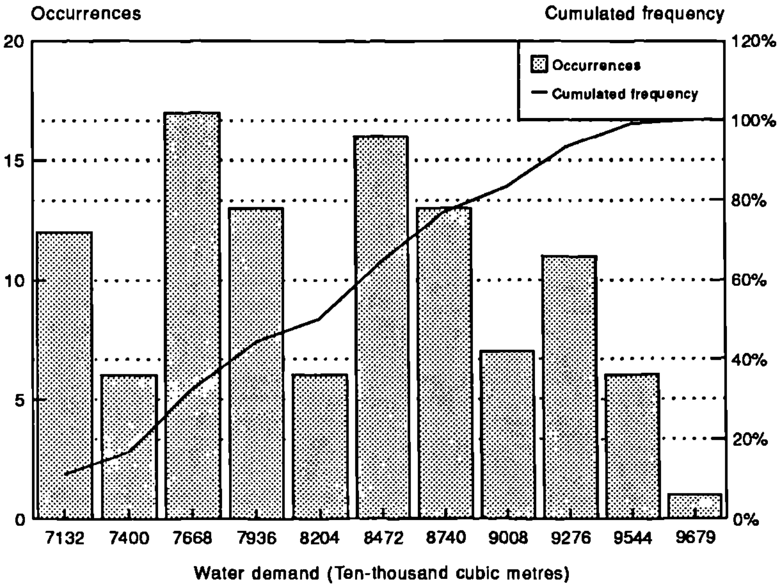


Figure 11.2 Forecasted residential water use in year 2000

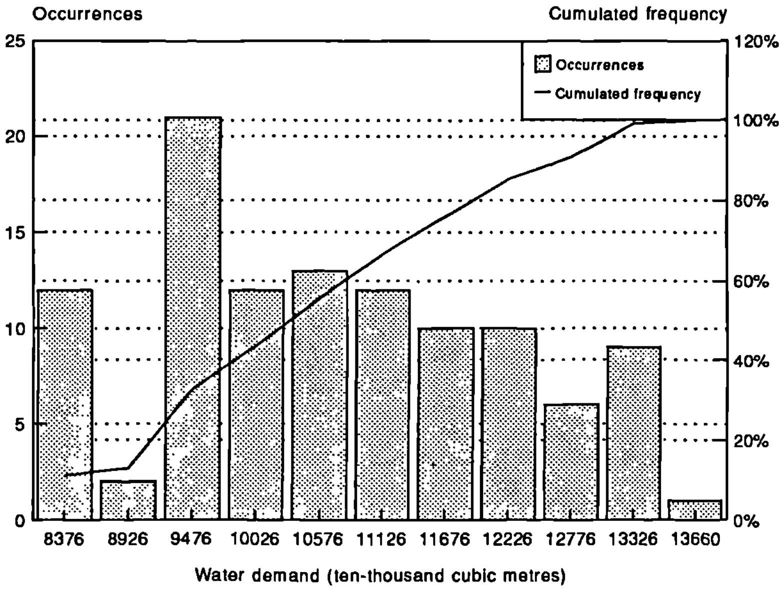


Figure 11.3 Forecasted residential water use in year 2010

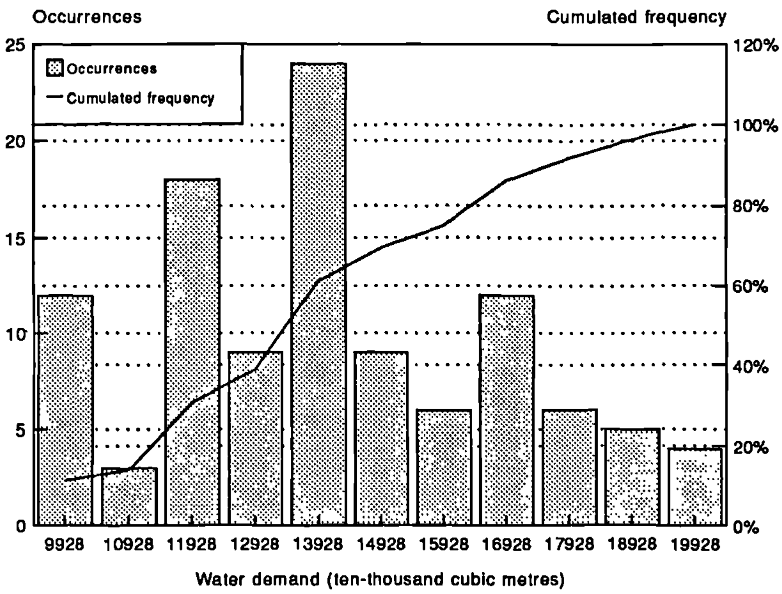


Figure 11.4 Forecasted residential water use in year 2020

about 30 percent of the total value of industrial product, and consume over a quarter of the total industrial water use. Although the thermoelectrical plant produces only 6 percent of the total value of industrial product, it consumes as much as 42 percent of the water required by the whole industries. Putting them together, chemical, petrol and thermoelectrical industries in Lanzhou consume nearly 75 percent of industrial water use. In order to make the forecast more explicit, industrial water use in this case study is further divided into four sub-sectors: chemical, petrol, thermoelectrical, and other industries. The method used for each of these sub-sectors is as described in Section 10.3.

The names of the variables, parameters, and initial variables used in the sub-subroutine are added an extra letter: C, E, P and O, to indicate chemical, thermoelectrical, petrol and other industries respectively. For examples, AVCDR is the AVDR (annual increase rate of industrial productive value) for the chemical industry; AVERR is the AVRR (annual increase rate of water reuse rate as a fraction of 1-RUR.K) for the thermoelectrical industry; AVOVR indicates the AVVR (annual decrease rate of per unit value industrial water use) for the category of other industries, etc.

11.3.1 Determining Initial Values and Parameters

11.3.1.1 Determining the initial values

Since the industrial sector has been divided into four sub-sectors, except for NTIME, the number of initial variables will increase to be four times the original ones as described in Section 10.3. Therefore, there are four NPVQs--initial values of per unit value water use, four NINVs--initial values of gross industrial productive value, and four NRURs--initial values of water reuse rate.

The annual productive value of the sub-sectors are available from the city's statistics. In the water company's statistics, although the classification of industrial water use is not exactly what the case study requires, water supplied to the thermoelectric plant, to the infirmary, and to the two major chemical factories, can be recognized. The only problem is the values of water reuse rate in different sub-sectors. The water reuse rate for each of the sub-sectors in 1981 are obtained from Y. Ge (1983). However, no recent data is available. Based on the water reuse rate in 1981 and a forecast made by Y. Ge (1983), the values of NRURs in 1986 were estimated. Due to the problem with the NRURs, only one set of initial values is adopted for the industrial water demand forecast, with no other alternatives (see Table 11-4).

Table 11-4 Initial Values Accepted in the Industrial Subroutine

Ini-variables	Values Adopted	Ini-variables	Values Adopted
	Alternative 1		**Alternative 1**
NCPVQ	532	NORUR	0.55
NEPVQ	2454	NPRUR	0.89
NOPVQ	188.6	NCINV	92009
NPPVQ	70.7	NEINV	38916
NCRUR	0.895	NOINV	406038
NERUR	0.05	NPINV	108230
		NTIME	1986

11.3.1.2 Determining the parameters

In the Industrial Subroutine, there are only three parameters as given in Table 10-2. Due to disaggregation in the case study, twelve parameters are needed to be given values.

From the LCDP (CA-GI, 1992), the value of AVDRs from 1990 to 2010, and even 2020 for some categories, are available. Since it is a plan for the whole city rather than only the urban area which is covered in this case study, some adjustments are made.

For the chemical industry, the average annual increase rate of productive value (AVCDR) is predicted to be around 6 percent for the whole period of 1990-2000, 5 percent for 1990-2010, and 4 percent for the period of 1990-2020 in the LCDP (CA-GI, 1992, p31). Here, an adjustment is made to be 3 percent for the average increase rate during the period from 1986 to 2020. An alternative is also accepted, in which the value of AVCDR changes smoothly from 4 percent in 1986 to 3 percent in 1996, to 2 percent in 2006, no change from 2006 to 2016, and again reduce to 1 percent in 2026. The adjustments are made according to the plan in which a major development in chemical industry will be located outside the boundary of this study; and there is limited space for locating new industries in the urban area.

A similar adjustment is made for AVODR. According to the LCDP, as high as 10 percent annual increase rate of industrial productive value is derived for the category of 'other industries' for the period 1990 to 2010. For the same reason declared above, an average increase rate of 8 percent for the period 1986 to 2020 is accepted for AVODR; and then, an alternative that has decreasing values from 10 percent in 1986 to 2 percent in year 2026 with a decrease rate of 2 percent per ten years is adopted as well (see Table 11-5).

For the values of AVEDR and AVPDR, only an average annual increase rate of 2 percent is adopted for each of them. This is generally based on the LCDP. No other alternatives are adopted for them. The low increase rate of the petrol industry is restricted by both the environmental capacity of the urban area, and the long distance away from the oil fields. For the thermoelectrical power industry, several new hydroelectric power stations which can supply electricity to the city have been planned, and a few are under construction on the Yellow River, not far from Lanzhou. Therefore, it is not necessary to expand the capacity of thermoelectrical power generation, but to leave it as a source of power to make up the balance when supply for hydroelectricity is below the demand during the dry seasons. In addition, because air pollution in Lanzhou has already been a problem, for protecting the quality of natural environment, it would be necessary to restrict any expansion of thermoelectrical industry in the urban area.

For the AVVR, it was set for considering the effect of technological improvement only. In this case study, some other elements are concerned as well when estimating this parameter.

From the statistics of Lanzhou Water Company, it was found that water supplied to industrial users from 1981 to 1990 did not change much. In 1981, it was 216.5 million cubic metres, compared with 221.97 million cubic metres in 1990. However, the industrial productive value increased dramatically during this period. In 1980, the productive value within the area studied was 2.94 billion Yuan; in 1990 it increased to 8.89 billion Yuan. Although around 10 percent of water used by industries that was supplied by factories themselves was not taken into account, the unparalleled changes in water use and productive value cannot be totally explained. The improvement in industrial technologies should have some contribution to this, but there must be some other reasons.

It was found that there are two more factors which may be responsible for this big gap. They are quite related to the Chinese economic system and the current economic reform. Firstly, since 1980s, the factories have been eager to develop new products based on their old bases. Some factories that used to produce raw materials for other industries started to make use of the material to produce some simple, complete products by themselves. Meanwhile, most of the newly developed industries in the area are based on the original ones, and they try to make use of the material products instead of selling them outside of the area, which was the way it used to be. This is mainly caused by the big difference between the price of material products, which was controlled by the central government, and the price of the complete products, which was almost uncontrolled by the government. The gross productive value increased rapidly due to this change, while water use increased very little. Secondly, the price of industrial products has increased several, even more than ten, times since 1980. Although all the annual industrial productive values are in terms of 1980's prices, in fact, they are calculated by dividing them with a price index. It is felt that the index will not properly reflect the effect of the real increase in prices.

Therefore, in this case study, determining the value of AVVRs not only considers the technological improvement but the change inside the industrial structure and some effects of price increase as well. Because of the uncertainty involved in these, two alternative values are adopted for each of the AVVRs (AVCVR, AVEVR, AVOVR, and AVPVR) (see Table 11-5)

Another group of parameters is about the annual increase rate of water reuse rate, or the AVRRs. The current water reuse rate in chemical and petrol industry is already very high, up to 89 percent. It is not realistic to hope them to be much higher. Although water reuse rate in the thermoelectrical plant is quite low, there are certain limitations for having a fast increase. Referring again to the forecast made by Y. Ge (1983), an annual increase rate of 0.5 percent, in terms of 1-RUR.K, is assumed for AVERR and AVORR; and 0.2 percent is assumed for AVCRR and AVPRR. No alternative values are adopted for these (see Table 11-5).

Table 11-5 Values Adopted for Parameters in the Industrial Subroutine

Parameters	Alternative Values Adopted	
	Alternative 1	**Alternative 2**
1. AVCDR	(TIME:1986-2026, 10) 0.04/0.03/0.02/0.02/0.01	0.03
2. AVEDR	0.02	
3. AVODR	(TIME:1986-2026, 10) 0.10/0.08/0.06/0.04/0.02	0.08
4. AVPDR	0.02	
5. AVCVR	-0.01	-0.02
6. AVEVR	-0.019	-0.01
7. AVOVR	-0.02	-0.01
8. AVPVR	-0.002	-0.005
9. AVCRR	0.002	
10. AVERR	0.005	
11. AVORR	0.005	
12. AVPRR	0.002	

11.3.2 The Simulation Model

Following is the complete computerized simulation model used for forecasting industrial water use, in which shows the four major parts corresponding to the four sub-sectors.

FORECASTING INDUSTRIAL WATER USE

WATER USE IN ELECTRICAL INDUSTRY

```
L ERUR.K=ERUR.J+DT*RERUR.JK
NOTE WATER REUSE RATE IN ELECTRICAL INDUSTRY (fraction)
N ERUR=NERUR
C NERUR=0.05
R RERUR.KL=(1-ERUR.K)*AVERR
P AVERR=0.005
NOTE ANNUAL INCREASE RATE OF WATER REUSE RATE
L EPVQ.K=EPVQ.J+DT*(REPVQ.JK)
NOTE UNIT VALUE WATER USE (cubic metres/ten-thousand yuan)
N EPVQ=NEPVQ
C NEPVQ=2450
R REPVQ.KL=EPVQ.K*AVEVR
P AVEVR=-0.019
NOTE ANNUAL DECREASE RATE OF PER UNIT VALUE WATER USE
A AEPVQ1.K=EPVQ.K*(1-ERUR.K)/(1-NERUR)
NOTE UNIT VALUE WATER USE ADJUSTED BY REUSE RATE
```

```
A EINDQ.K=AEPVQ1.K*EINV.K
NOTE ANNUAL INDUSTYRIAL WATER USE (cubic metres)
N EINV=NEINV
C NEINV=38916
L EINV.K=EINV.J+DT*(REINV.JK)
NOTE INDUSTRIAL PRODUCTIVE VALUE (ten-thousand yuan)
R REINV.KL=EINV.K*AVEDR
P AVEDR=0.02
NOTE ANNUAL INCREASE RATE OF PRODUCTIVE VALUE
```

WATER USE IN CHEMICAL INDUSTRY

```
L CRUR.K=CRUR.J+DT*(RCRUR.JK)
NOTE INDUSTRIAL WATER REUSE RATE (fraction)
N CRUR=NCRUR
C NCRUR=0.895
R RCRUR.KL=(1-CRUR.K)*AVCRR
P AVCRR=0.002
NOTE ANNUAL INCREASE RATE OF WATER REUSE RATE
L CPVQ.K=CPVQ.J+DT*(RCPVQ.JK)
NOTE UNIT VALUE WATER USE (cubic metres/ten-thousand yuan)
N CPVQ=NCPVQ
C NCPVQ=532
R RCPVQ.KL=CPVQ.K*AVCVR
P AVCVR=-0.01
NOTE ANNUAL DECREASE RATE OF PER UNIT VALUE WATER USE
A ACPVQ1.K=CPVQ.K*(1-CRUR.K)/(1-NCRUR)
NOTE UNIT VALUE WATER USE ADJUSTED BY REUSE RATE
A CINDQ.K=ACPVQ1.K*CINV.K
NOTE ANNUAL INDUSTYRIAL WATER USE (cubic metres)
N CINV=NCINV
C NCINV=92009
L CINV.K=CINV.J+DT*(RCINV.JK)
NOTE INDUSTRIAL PRODUCTIVE VALUE (ten-thousand yuan)
R RCINV.KL=CINV.K*AVCDR.K
A AVCDR.K=TABLE(TAVCDR,TIME.K,1986,2026,10)
T TAVCDR=0.04/0.03/0.02/0.02/0.01
NOTE ANNUAL INCREASE RATE OF CHEMICAL PRODUCTIVE VALUE
```

WATER USE IN PETROLEUM INDUSTRY

```
L PRUR.K=PRUR.J+DT*(RPRUR.JK)
NOTE INDUSTRIAL WATER REUSE RATE (fraction)
N PRUR=NPRUR
C NPRUR=0.89
R RPRUR.KL=(1-PRUR.K)*AVPRR
P AVPRR=0.002
NOTE ANNUAL INCREASE RATE OF WATER REUSE RATE
L PPVQ.K=PPVQ.J+DT*(RPPVQ.JK)
NOTE UNIT VALUE WATER USE (cubic metres/ten-thousand yuan)
N PPVQ=NPPVQ
C NPPVQ=70.7
R RPPVQ.KL=PPVQ.K*AVPVR
P AVPVR=-0.002
NOTE ANNUAL DECREASE RATE OF PER UNIT VALUE WATER USE
A APPVQ1.K=PPVQ.K*(1-PRUR.K)/(1-NPRUR)
NOTE UNIT VALUE WATER USE ADJUSTED BY WATER REUSE RATE
A PINDQ.K=APPVQ1.K*PINV.K
NOTE ANNUAL WATER USE BY PETROL INDUSTRY (cubic metres)
N PINV=NPINV
```

```
C NPINV=108230
L PINV.K=PINV.J+DT*(RPINV.JK)
NOTE PETROLEUM PRODUCTIVE VALUE (ten-thousand yuan)
R RPINV.KL=PINV.K*AVPDR
P AVPDR=0.02
NOTE ANNUAL INCREASE RATE OF PETROLEUM PRODUCTIVE VALUE

 WATER USE IN OTHER INDUSTRIES
L ORUR.K=ORUR.J+DT*(RORUR.JK)
NOTE INDUSTRIAL WATER REUSE RATE (fraction)
N ORUR=NORUR
C NORUR=0.55
R RORUR.KL=(1-ORUR.K)*AVORR
P AVORR=0.005
NOTE ANNUAL INCREASE RATE OF WATER REUSE RATE
L OPVQ.K=OPVQ.J+DT*(ROPVQ.JK)
NOTE UNIT VALUE WATER USE (cubic metres/ten-thousand yuan)
N OPVQ=NOPVQ
C NOPVQ=188.6
R ROPVQ.KL=OPVQ.K*AVOVR
P AVOVR=-0.02
NOTE ANNUAL DECREASE RATE OF PER UNIT VALUE WATER USE
A AOPVQ1.K=OPVQ.K*(1-ORUR.K)/(1-NORUR)
NOTE UNIT VALUE WATER USE ADJUSTED BY REUSE RATE
A OINDQ.K=AOPVQ1.K*OINV.K
NOTE WATER USE IN OTHER INDUSTRIES (cubic metres/year)
N OINV=NOINV
C NOINV=406038
L OINV.K=OINV.J+DT*(ROINV.JK)
NOTE GROSS PRODUCTIVE VALUE (ten-thousand yuan)
R ROINV.KL=OINV.K*AVODR.K
A AVODR.K=TABLE(TAVODR,TIME.K,1986,2026,10)
T TAVODR=0.1/0.08/0.06/0.04/0.02
NOTE ANNUAL INCREASE RATE OF GROSS PRODUCTIVE VALUE

A INDQ.K=EINDQ.K+CINDQ.K+PINDQ.K+OINDQ.K
A INV.K=EINV.K+CINV.K+PINV.K+OINV.K
A PVQ.K=INDQ.K/INV.K
N TIME=1986
SPEC DT=1/LENGTH=2020/SAVPER=1
RUN
```

11.3.3 The Result of Forecast

In total, sixty-four alternative combinations are obtained from the alternative values given to the initial variables and parameters in the industrial subroutine that were presented in Table 11-4 and Table 11-5. The number of all possible combinations can be calculated by 1*2*1*2*1*2*2*2*2*1*1*1*1=64, in which the number underlined represents the number of set of initial values, and the following series are the number of alternative values of the parameters from AVCDR to AVPRR listed in Table 11-5. Running the simulation model described in the last section for each of the combinations, sixty-four scenarios can be obtained for each coming year. Table C-2 (in Appendix C) lists the total alternative futures obtained for the years 2000, 2010, and 2020. The statistics of the forecasted industrial water use in year 2000, 2010, and 2020 are presented in Table 11-6. The histogram of industrial water use in these three years are shown in Figure 11.5 to Figure 11.7.

Table 11-6 Statistics of Forecasted Industrial Water Use (in 10^4 m^3)

For-Year	Mean	Std err	S.E/Mean	Std dev	Skewness	Range
2000	34261.41	208.70	0.006	1669.57	0.120	6520
2010	46315.94	494.46	0.011	3955.71	0.103	13040
2020	62364.06	1550.03	0.025	12400.20	0.381	40010

11.4 FORECASTING THE AGRICULTURAL WATER DEMAND

Since the climate is semi-arid, and the annual precipitation is only 327.7 mm on average, irrigation is very important for agricultural activities in Lanzhou area. After years of effort on developing irrigation projects, up to 1989, the total irrigated area had been 120 thousand mu (one mu equals one fifteenth ha.), of which 44 thousand mu was located in the area of low flat land (referred as LFL hereafter) along the Yellow River valley where farming practice has been to divert water from the river to irrigate the farm land for hundreds of years. The remainder was the new irrigated area developed by building water pumping stations and transferring projects since 1950s, in which about 8 thousand mu was irrigated by using the spray method.

The farm land in the LFL, which is mainly used for vegetable and fruit production, is reducing because of the growth of the urban area. From 1982 to 1989, for example, 24 thousand mu of irrigated farm land in the LFL area was lost to urbanization (Lanzhou City Statistical Bureau, 1982, 1990). The new

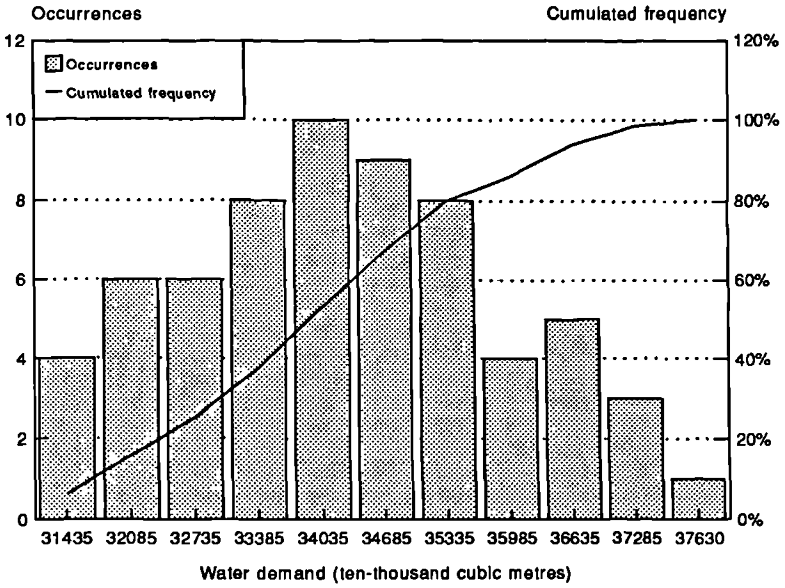


Figure 11.5 Forecasted industrial water use in year 2000

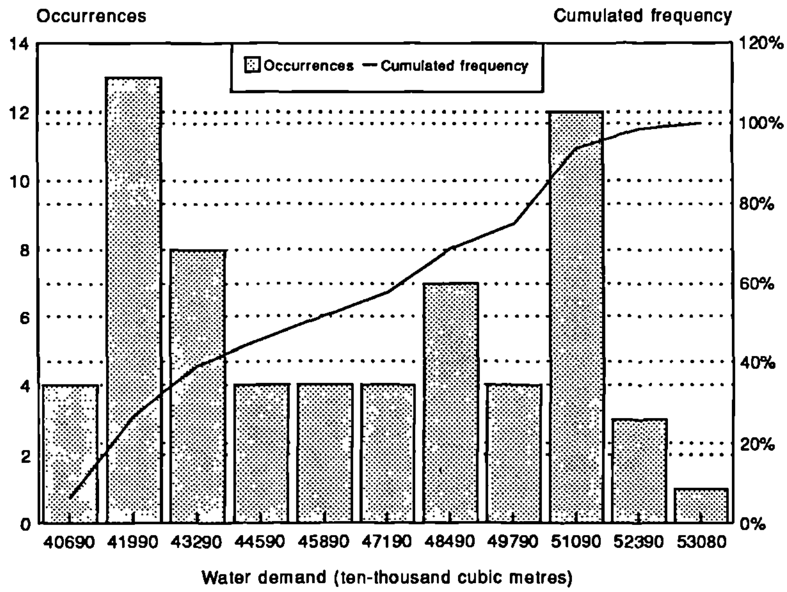


Figure 11.6 Forecasted industrial water use in year 2010

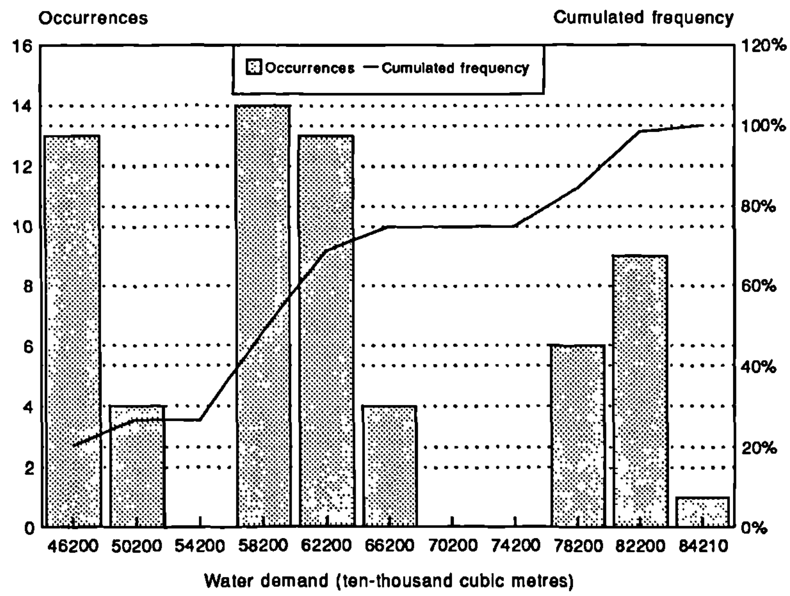


Figure 11.7 Forecasted industrial water use in year 2020

developed irrigated areas are in higher and more distant locations, even terraced fields around hills, which are mainly used for grain production. Effort is still being spent on developing new irrigated areas in the hills.

Agricultural water use is independent of the public water supply system so that there is no information about it available from the water company. And furthermore, there is no regular record of agricultural water use. All the information obtained is from several reports of investigations and studies. Under this situation, it is not possible to attempt any disaggregate forecast, although it is preferable to distinguish the area used for vegetable production from that used for grain production, or to distinguish the LFL from other irrigated areas. Therefore, the model described in Section 10.4 is applied to this case study without any particular adjustment.

11.4.1 Determining Initial Values and Parameters

11.4.1.1 Determining the initial values

Since the limitation in data availability, only one value is adopted for each of the initial variables, without any alternative set. Keeping the same with the other subroutines, 1986 is chosen as NTIME. The value of NIAR is adopted from the Lanzhou City Statistical Year-book (Lanzhou City Statistical Bureau, 1987). NPAQ and NECA are estimated according to a report of investigation on agricultural water use and project management, undertaken during 1981-84 by the provincial water authority (GWA, 1984). The value of NWIAR is decided after confirming that there is no waste water irrigation up to 1992 in Lanzhou by the experts of Lanzhou Water Resources and Engineering Institute who were interviewed by this author in October 1992. The information was that Lanzhou urban area is so narrow in the valley of Yellow River, and the potential sources of urban waste water, the major industries, are so close to the river that it is more convenient for farmers to draw water from the river than from factories. The values adopted for the above initial variables are presented in Table 11-7.

Table 11-7 Initial Values Accepted in the Agricultural Subroutine

Ini-variable	Values Adopted	Ini-variable	Values Adopted
	Alternative 1		**Alternative 1**
NPAQ	500	NWIAR	0.0
NIAR	120800	NECA	0.57
		NTIME	1986

11.4.1.2 Determining the parameters

Limited information about agricultural water use increases the difficulties to estimate the value of parameters accurately and convincingly. Referring to LCDP on urban land use planning (CA-GI, 1992), two trends exist: the continued decrease in the LFL farm land and the increase in new developed irrigated area. Three alternative values are assumed for the parameter of AVIAR: (1) a slower increase rate; (2) zero increase; and (3) a slower decrease rate. In the case where waste water will be used at a small scale in Lanzhou, an alternative value is also adopted for CWIAR, besides assuming that the current situation continues. The improvements in irrigation methods, soil water conservation technology, and water transferring technique will greatly influence the per unit area water use and canal efficiency. However, there are many uncertainties around them. Here, only a negative value (-0.01) is assumed for AVATR, but no other alternatives. For AVECR, a value of 0.05 is accepted, and another series of values that change with ECA is accepted as an alternative. During the process of determining AVECR, the simulation model is helpful in terms of choosing a proper value which results in an acceptable value of ECA which may be treated as a target for a certain coming year. The effect of climate, CCDQ and CCHQ, are determined based on the information of local climatic change, and by referring to Yang, Ren, et al (1984, P69-72) (see Table 11-8).

Table 11-8 Values Adopted for the Parameters in the Agricultural Subroutine

Parameters	Alternative Values Adopted		
	Alternative 1	***Alternative 2***	***Alternative 3***
1. AVATR	-0.01		
2. CCDQ	50		
3. CCHQ	35		
4. AVIAR	0.001	0.0	-0.001
5. CWIAR	0.0	50	
6. AVECR	(ECA:0.5-1.0, 0.1) 0.05/0.04/0.03/0.02/0.01/0	0.05	

11.4.2 The Simulation Model

The complete computerized simulation model used for forecasting agricultural water use is given as follows. It can be run when combine it with the package of Professional DYNAMO. The numbers given in the model is only one possible combination of the values listed in Table 11-7 and 11-6.

AGRICULTURAL WATER USE FORECASTING

```
L PAQ.K=PAQ.J+DT*(RPAQ.JK)
NOTE UNIT AREA ANNUAL WATER USE (cubic metres/mu)
N PAQ=NPAQ
C NPAQ=500
R RPAQ.KL=PAQ.K*AVATR
NOTE CHANGE OF UNIT AREA WATER USE (cubic metres/mu/year)
P AVATR=-0.01
NOTE CHANGE RATE OF UNIT AREA WATER USE (fraction)
A APAQ1.K=PAQ.K*NECA/ECA.K
NOTE UNIT AREA WATER USE ADJUSTED BY CANNAL EFFICIENCY
L ECA.K=ECA.J+DT*(RECA.JK)
NOTE CANNAL EFFICIENCY (percentage)
N ECA=NECA
C NECA=0.57
R RECA.KL=(1-ECA.K)*AVECR.K
A AVECR.K=TABLE(TAVECR,ECA.K,0.5,1.0,0.1)
T TAVECR=0.05/0.04/0.03/0.02/0.01/0
NOTE ANNUAL INCREASE RATE OF CANNAL EFFICIENCY (fraction)
A DPAQ.K=APAQ1.K+CCDQ
NOTE UNIT AREA WATER USE IN DRY YEAR (cubic metres/mu)
P CCDQ=50
A HPAQ.K=APAQ1.K-CCHQ
NOTE UNIT AREA WATER USE IN HUMID YEAR (cubic metres/mu)
P CCHQ=35
A AGRQ.K=APAQ1.K*IAR.K
```

```
NOTE AGRICULTURAL WATER USE IN NORMAL YEAR (cubic metres)
A DAGRQ.K=DPAQ.K*IAR.K
NOTE AGRICULTURAL WATER USE IN DRY YEAR (cubic metres)
A HAGRQ.K=HPAQ.K*IAR.K
NOTE AGRICULTURAL WATER USE IN HUMID YEAR (cubic metres)
N GIAR=NIAR
C NIAR=120800
L GIAR.K=GIAR.J+DT*(RIAR.JK)
NOTE TOTAL IRRIGATED AREA (mu)
R RIAR.KL=GIAR.K*AVIAR
P AVIAR=0.001
NOTE ANNUAL INCREASE RATE OF IRRIGATED AREA (fraction)
L WIAR.K=WIAR.J+DT*RWIAR.JK
NOTE AREA IRRIGATED BY WASTE WATER (mu)
R RWIAR.KL=CWIAR
P CWIAR=0
N WIAR=NWIAR
C NWIAR=0
A IAR.K=GIAR.K-WIAR.K
NOTE AREA IRRIGATED BY USING FRESH WATER (mu)
N TIME=1986
SPEC DT=1/LENGTH=2020/SAVPER=1
RUN
```

11.4.3 The Result of Forecast

From the alternative values given to the parameters presented in Table 11-8, and the set of initial values listed in Table 11-7, twelve alternative combinations can be constructed for agricultural water use. Running the model described in the above section for each of the possible combinations, therefore, twelve results will be obtained for each of the variables described in the model and for any coming year. Considering the agricultural water use in a dry year, normal year, and then in a humid year, and taking these as alternative futures as well, there will be a total of thirty-six alternative futures for agricultural water use for each coming year (see Table C-3 in Appendix C). After statistical analysis, some statistics for projected agricultural water use in the years 2000, 2010, and 2020 are presented in Table 11-9. The frequency distribution of agricultural water use in these three years are described by the respective histograms (see Figure 11.8 to Figure 11.10).

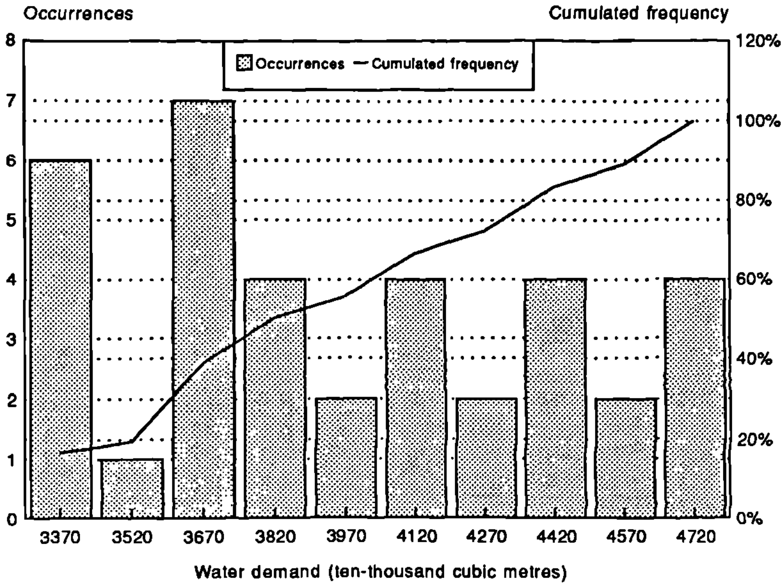


Figure 11.8 Forecasted agricultural water use in year 2000

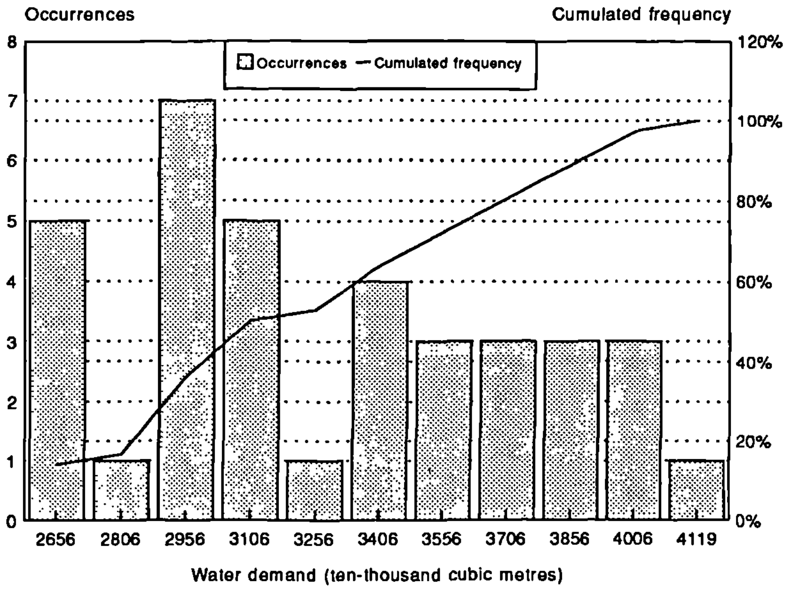


Figure 11.9 Forecasted agricultural water use in year 2010

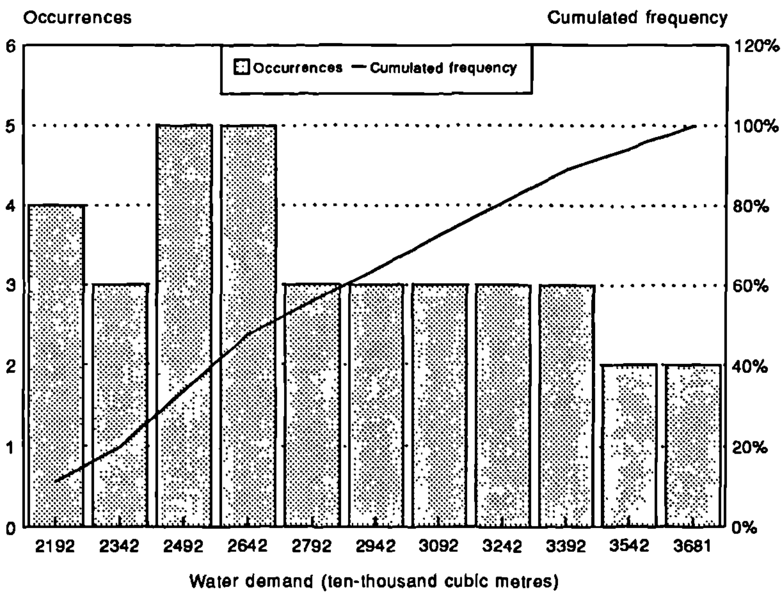


Figure 11.10 Forecasted agricultural water use in year 2020

Table 11-9 Statistics of Forecasted Agricultural Water Use (in 10^4 m^3)

For-Year	Mean	Std err	S.E/Mean	Std dev	Skewness	Range
2000	3975.81	75.39	0.019	452.35	0.193	1444
2010	3298.31	76.94	0.023	461.60	0.199	1538
2020	2840.92	76.64	0.027	459.83	0.206	1564

11.5 FORECASTING THE COMMERCIAL WATER DEMAND

In the data, commercial water use used to be combined with residential water use. Since 1986, fortunately, Lanzhou Water Company started to take records of commercial water use separately, because a higher water price for it was then charged; higher than for residential and industrial use. The short historical data available from 1986 to 1990 is the most important, but limited, information for this study. Thus, no attempt is made towards any further disaggregation, but simply to completely adopt the model described in Section 10.5.

11.5.1 Determining Initial Values and Parameters

11.5.1.1 Determining the initial values

Three of the four initial variables in the commercial subroutine appear in the residential subroutine. They are NPOP, NINC, and NTIME. A variable should be identical in the same case study. Therefore, the values adopted for them in forecasting commercial water use are exactly the same as those adopted in the residential subroutine. The only different one is NPCMQ, for which two values are accepted to be corresponding to the previous three variables. Its value is obtained by dividing the commercial water use by the number of population served, which are available in the water company's statistics. For estimating a three-year-average value, commercial water use in 1985, which is not available in the company's statistics, was estimated according to the percentage of commercial water use over residential water use in 1986 and 1987. All the initial values accepted are listed in Table 11-10.

Table 11-10 Initial Values Accepted in the Commercial Subroutine

Initial Variables	Alternative Values Adopted	
	Alternative 1	**Alternative 2**
NPCMQ	24.95	31.2
NPOP	981363	993613
NINC	942	872.2
NTIME	1986	1986 (85-87 average)

11.5.1.2 Determining the parameters

There are five parameters in the commercial subroutine as listed in Table 10-4, in which three of them have already been determined in the residential subroutine. The values that were adopted for them, including the alternatives, are accepted for the forecasting of commercial water use forecast. Thus, only two parameters are needed to be determined: EPCP and EPCI.

Based on the water company's records (1986-1990) and the available data of INC, regression analyses between the logarithmic form PCMQ and the logarithmic form POP, and the logarithmic form INC were undertaken. When a multiple regression was attempted, only one independent variable, POP, was taken into account, while the correlation coefficient was already as high as 0.999, which must have been caused by the small number of cases analysed (only five). A single regression with the other variable rejected by the multiple regression also resulted in a high correlation coefficient, up to 0.91. From the single logarithm form regression analysis, the estimated value of EPCP is as high as 4, and the estimated value of EPCI is about 1. If they appear simultaneously in an equation, like Equation 10.48, only half of the above estimated values should be adopted. Since the time series used for these analyses is too short, some subjective adjustments are made to them for the long-term forecasting model. For EPCP, a group of values which decrease with

TIME are assumed; and for EPCI two constant alternatives are accepted. (see Table 11-11)

Table 11-11 Values Adopted for Parameters in the Commercial Subroutine

Parameters	Alternative Values Adopted		
	Alternative 1	**Alternative 2**	**Alternative 3**
1. EPCP	(TIME:1986-2026, 10) 2.0/1.5/1.0/0.7/0.5		
2. EPCI	0.4	0.2	
3. CPIM	14000	20000	6500
4. AVPR	0.012	0.0137	0.011
5. AVIR	0.05	(TIME:1986-2026, 10) 0.06/0.05/0.04/0.03/0.02	

11.5.2 The Simulation Model

The computerized simulation model used for forecasting commercial water use is presented below. It should also be mentioned that the values given to the initial variables and parameters are just one example of the possible combinations.

COMMERCIAL WATER DEMAND FORECASTING

```
A PCMQ.K=NPCMQ*(POP.K/NPOP)**EPCP.K*(INC.K/NINC)**EPCI
A EPCP.K=TABLE(TEPCP,TIME.K,1986,2026,10)
T TEPCP=2/1.5/1/0.7/0.5
P EPCI=0.4
NOTE PER CAPITA COMMERCIAL WATER USE (litres/capita/day)
C NPCMQ=31.2
L INC.K=INC.J+DT*RINC.JK
NOTE PER CAPITA ANNUAL INCOME (yuan/capita)
R RINC.KL=INC.K*AVIR.K
A AVIR.K=TABLE(TAVIR,TIME.K,1986,2026,10)
T TAVIR=0.06/0.05/0/04/0.03/0.02
N INC=NINC
C NINC=872.2
L POP.K=POP.J+DT*(RPIM.JK+RPIN.JK)
NOTE NUMBER OF POPULATION (persons)
N POP=NPOP
C NPOP=993613
R RPIN.KL=POP.K*AVPR
P AVPR=0.012
```

```
R RPIM.KL=CPIM
C CPIM=14000
A COMQ.K=PCMQ.K*POP.K*365/1000
NOTE ANNUAL COMMERCIAL WATER USE (cubic metres)
N TIME=1986
SPEC DT=1/LENGTH=2021/SAVPER=1
RUN
```

11.5.3 The Result of Forecast

Running the simulation model described in the above section, twenty-four alternative futures can be resulted from different combinations of the parameters and sets of initial values given. The total number of alternative futures can be obtained by calculating: 2*1*2*3*2=24, where the "2" is the number of set of initial values, "3" is the fixed combinations of CPIM and AVPR that was explained before, and the other three numbers represent the number of alternative values adopted for the other three parameters. (see Tale 11-10 and Table 11-11). Analysing the results obtained from the simulations, the statistics of commercial water use in the years 2000, 2010, and 2020 are presented in Table 11-12, while the whole alternative forecasts for these years are given in Table C-4 in Appendix C. The frequency distribution of commercial water use in these years are presented by histograms, which are shown in Figure 11.11, Figure 11.12, and Figure 11.13.

Table 11-12 Statistics of Forecasted Commercial Water Use (in 10^4 m^3)

For-Year	Mean	Std err	S.E/Mean	Std dev	Skewness	Range
2000	2751.83	138.14	0.050	676.77	0.674	2560
2010	4035.54	225.82	0.056	1106.27	0.479	4019
2020	5446.54	348.05	0.064	1705.07	0.591	6520

11.6 EVALUATING THE PERFORMANCE OF THE MODEL

After applying the model to a case study, its performance can be evaluated. Here, the evaluation is made from three aspects: (1) the variation in the forecast

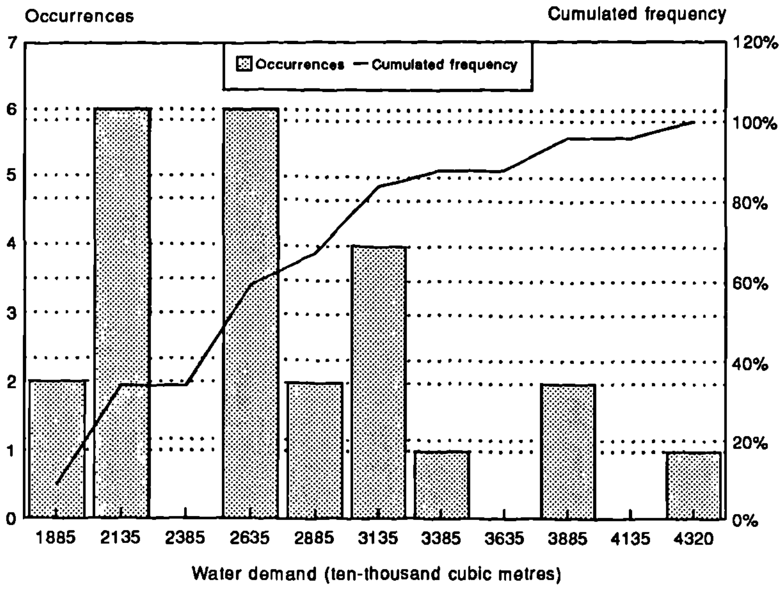


Figure 11.11 Forecasted commercial water use in year 2000

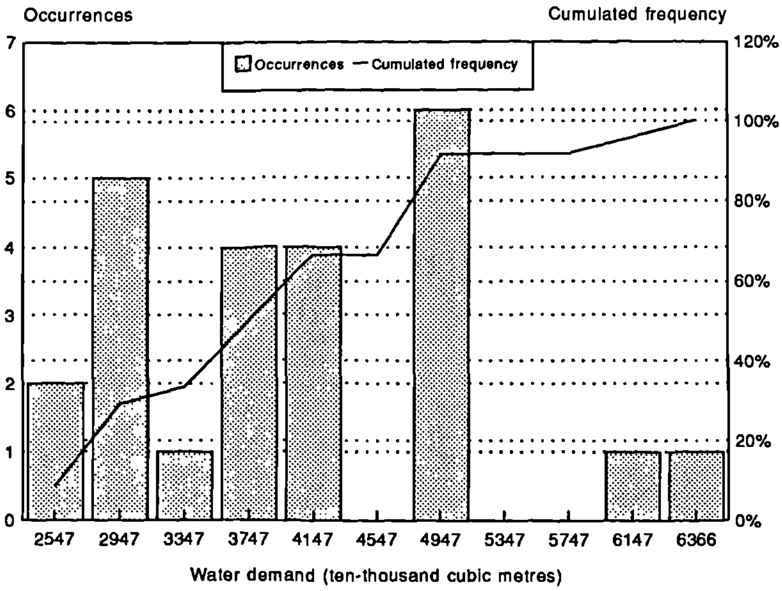


Figure 11.12 Forecasted commercial water use in year 2010

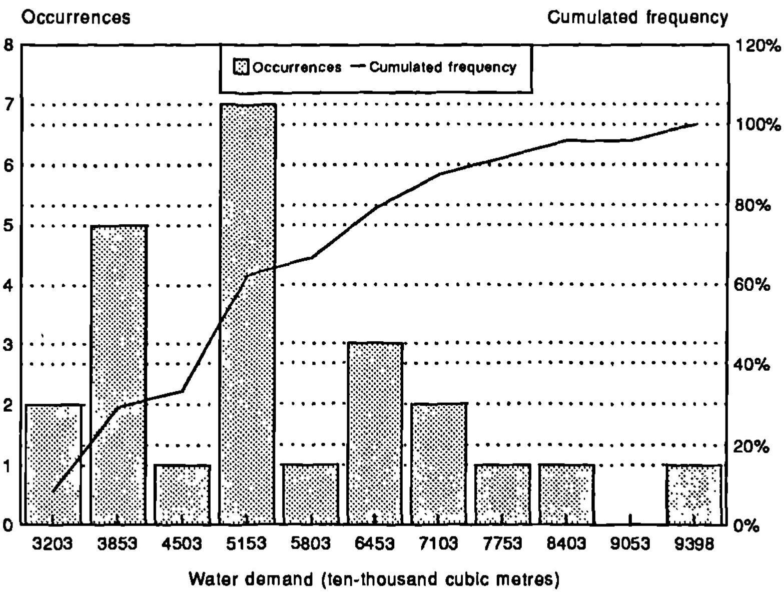


Figure 11.13 Forecasted commercial water use in year 2020

results; (2) sensitivity analysis; and (3) comparisons between the forecasted water uses and the historical records which are available from 1987 to 1990.

11.6.1 The Variance of the Forecasted Results

The statistical analysis on the results of the alternative forecasts reveals that the Standard error and Range increase with the horizon of forecast. Taking residential water use for example, the quotient of Standard error over the Mean increases from 0.8% in 2000, to 1.36% in 2010, and to 1.91% in 2020 (details see Tables: 11-3, 11-6, 11-9, and 11-12). This confirms the principle that the further the forecast, the more the uncertainty is.

The variance of the forecasted results is influenced by the alternative values adopted for the parameters. When quite different alternatives are adopted for the parameters, running the simulation model will produce very changeable results. When there is much uncertainty around the parameters, people usually like to estimate their ranges. The alternatives chosen are more likely to be the ends of a range rather than any number between them. Therefore, if such a group of alternative futures obtained is presented by a histogram, its shape is not necessarily like a normal curve, as what Whitford (1972) concluded, especially when there is a small number of alternative futures, less than fifty cases, for example. The occurrences may be concentrated on the two sides rather than the centre of a histogram, and skewness is quite usual. When a big range exists in the results of a forecast, occurrences may not be evenly distributed within this range, but gathered at some parts, as shown in Figure 11.6.

Therefore, care should be paid to determining the parameters. When there is much uncertainty about the alternatives chosen, it is necessary to give much thought to making an assumption. An upper limit should also be considered for the forecast time horizon, in order to get reliable results by using this model. In this case, thirty years ahead from the base year is the suggested answer.

11.6.2 Sensitivity Analysis

From Table 11-13, it can be seen that wide ranges of water demand have been forecasted for the future time, commercial water demand in particular. This is caused by the choice of alternative values for the parameters to reflect uncertainty.

Table 11-13 Forecasted Water Demand in Lanzhou Urban Area Compared to Its Water Use in the Base Year (1986)

Sectors		Year 2000	Year 2010	Year 2020
Residential	(%)	42 - 97	65 - 178	92 - 312
Industrial	(%)	36 - 65	75 - 132	93 - 268
Agricultural	(%)	-22 - -45	-32 - -57	-39 - -65
Commercial	(%)	88 - 373	163 - 612	222 - 952

Different parameters play different roles in influencing the variation of water demand forecasts. A sensitivity analysis has been undertaken to see how a certain change in each of the parameters, 10 percent for example, will cause a corresponding change in future water demand. The results of sensitivity analysis on the parameters in the residential, industrial, agricultural and commercial subroutines are presented in Table 11-14 to Table 11-17.

The sensitivity analysis shows that the model is more sensitive to changes in some parameters than that in others. The percentage of change in future water demand caused by a 10% change in a parameter, is determined by the time horizon, the value estimated for the parameter, and the significance of the factor that the parameter represented or related.

Table 11-14 Sensitivity Analysis on Parameters in the Residential Subroutine

Parameters	Values Adopted for parameters	Change in parameters (%)	Change in forecasted water use 2000 (%)	2010 (%)	2020 (%)
CPAI	0.0127	10	0.83	1.45	2.18
CPAF	-5.6	10	0.23	0.27	0.28
PCSM	0.025	10	-0.25	-0.27	-0.42
CPIM	14000	10	1.55	2.26	2.88
AVPR	0.012	10	1.54	2.53	3.58
AVIR	TIME:(1986-2026, 10) 0.06/0.05/0.04/0.03/0.02	10	1.18	2.53	4.28
AVFR	(FAS:3.8-2.8, -0.2) -0.026/-0.02/-0.02/-0.015/-0.01/-0.005	10	0.11	0.09	0.07
AVSR	(PWS:0.8-1.0, 0.05) 0.05/0.03/0.03/0.01/0	10	-0.60	-0.63	-0.42

Table 11-15 Sensitivity Analysis on Parameters in the Industrial Subroutine

Parameters	Values Adopted for parameters	Change in parameters (%)	Change in forecasted water use 2000 (%)	2010 (%)	2020 (%)
AVCDR	(TIME:1986-2026, 10) 0.04/0.03/0.02/0.02/0.01	10	0.92	1.20	1.48
AVEDR	0.02	10	0.74	0.98	1.20
AVODR	(TIME:1986-2026, 10) 0.1/0.08/0.06/0.04/0.02	10	6.07	11.03	14.08
AVPDR	0.02	10	0.09	0.12	0.19
AVCVR	-0.01	10	-0.27	-0.43	-0.58
AVEVR	-0.019	10	-0.71	-0.94	-1.14
AVOVR	-0.02	10	-1.42	-2.58	-4.23
AVPVR	-0.002	10	-0.00	-0.02	-0.02
AVCRR	0.002	10	-0.03	-0.10	-0.13
AVERR	0.005	10	-0.18	-0.26	-0.30
AVORR	0.005	10	-0.36	-0.72	-1.07
AVPRR	0.002	10	-0.00	-0.02	-0.02

Table 11-16 Sensitivity Analysis on Parameters in Agricultural Subroutine

Parameters	Values Adopted for parameters	Change in parameters (%)	Change in forecasted water use 2000 (%)	2010 (%)	2020 (%)
AVATR	-0.01	10	-1.41	-2.40	-3.37
CCDQ	50	10	1.29	1.48	1.68
CCHQ	35	10	-1.16	-1.43	-1.68
AVIAR	0.001	10	0.15	0.23	0.33
CWIAR	0/50	10	0/-0.07	0/-0.09	0/-0.17
AVECR	(ECA:0.5-1.0, 0.1) 0.05/0.04/0.03/0.02/0.01/0	10	-1.36	-1.31	-1.18

Table 11-17 Sensitivity Analysis on Parameters in Commercial Subroutine

Parameters	Values Adopted for parameters	Change in parameters (%)	Change in forecasted water use 2000 (%)	2010 (%)	2020 (%)
EPCP	(TIME:1986-2026, 10) 2.0/1.5/1.0/0.7/0.5	10	4.44	4.92	4.70
EPCI	0.4	10	2.98	4.66	5.97
CPIM	14000	10	3.60	4.33	4.64
AVPR	0.012	10	3.56	4.87	5.81
AVIR	TIME:(1986-2026, 10) 0.06/0.05/0.04/0.03/0.02	10	2.86	4.53	5.81

In the residential subroutine, the parameters in relation to the factors of population and income, including CPIM, AVPR, AVIR and CPAI, are more responsible for the change in residential water use. In other words, the model is more sensitive to changes in these parameters. In the industrial subroutine, the parameters related to the 'other industries' sub-sector, i.e. AVODR, AVOVR and AVORR, play more important roles. This is because water demand by this industrial group in Lanzhou urban area is projected to increase much faster than the other three industrial sub-sectors. Future agricultural water demand is more sensitive to the change in AVATR and AVECR, which means technological improvements in irrigation and water transfer methods will greatly contribute to the change in agricultural water demand. Errors in estimation of CCDQ and CCHQ will result in comparatively higher errors in forecasting agricultural water demand in humid and dry years. Commercial water demand is very sensitive to the changes in all its parameters. A 10% error in any of the five parameters will result in an error between 2.86% and 4.44% in commercial water demand forecasting for year 2000, and an error between 4.70% and 5.97% for year 2020. This may be an explanation to the widest range of forecasted commercial water demand which is described in Table 12-13.

11.6.3 Comparisons between the Forecasts and Historical Records

From Lanzhou Water Company's statistics, annual records of residential, industrial, and commercial water use from 1987 to 1990 are available. Thus, comparisons between the recorded and the forecasted may be worthwhile for evaluating the performance of the model.

The values of forecasted water use adopted for comparison are not the Means of all alternative futures, but values from one alternative future. This makes the comparison simple and easier. The alternative future chosen to compare with the actual use is selected based on the least square principle. Let:

$$S_i = (Q_{0i}-M_0)^2 + (Q_{1i}-M_1)^2 + (Q_{2i}-M_2)^2 \qquad (11.1)$$

in which,

Q_{0i}: the ith alternative of projected water use in year 2000;
M_0: the mean of projected water use in year 2000;
Q_{1i}: the ith alternative of projected water use in year 2010;
M_1: the mean of projected water use in year 2010;
Q_{2i}: the ith alternative of projected water use in year 2020;
M_2: the mean of projected water use in year 2020;

The one that has the least value of S_i is selected to compare with the actual water use. For residential water use, it is one from a hundred and eight cases; for industrial water use, it is one from sixty-four; and for commercial water use, it is one chosen from twenty-four alternatives. The case selected in each sector is marked by using bold characters in Table C-1, C-2, and C-4 (Appendix C), from which the values adopted for the parameters and initial variables to obtain the scenarios can be found. The pairs of real water use and the forecasted are given in Table 11-18.

In residential water use, the projected values used to compare are the values of WREQ, which is the water use without adjustment by the factor of PCSM and PWS, because the corresponding real water use is from the water company, and the effect of water conservation policy can be neglected in a very short-term forecast. From the comparison, it can be found that the difference between what really occurred and the forecasts, i.e. the error term, is very small. The largest forecast error among the four pairs is only 3.8 percent of the actual residential water use. The smallest is only 1.4 percent.

In industrial water use, the forecasted INDQ is used to compare with the water company's records. The forecast error is larger and more varied compared with that obtained in the residential comparison. The largest forecast error is 14.2 percent of the actual industrial water use, and the smallest is 1.9 percent.

From Table 11-18, it can be seen that the real industrial water use changed dramatically from year to year, which may be the major reason which caused the variation in forecast error. Through investigation, it was found that the dramatic change in industrial water use was mainly from the thermoelectric industry. For example, water supplied to the thermal power plant in 1988 was 1289 ten thousand cubic metres, compared with only 865 ten thousand cubic metres in 1990. The reason for the change is much related to the role of the power plant in the regional electricity generation and supply system. As mentioned before, it is mainly an additional source of power to make up the balance of electricity requirement, i.e. backing up the hydroelectric power stations. During a dry year, it is used to generate more electricity than in a humid year when there is more water available to be used for hydroelectricity generation. And when the Plant generates more power, it consumes more water. If the factor of climate was taken into account in the sub-subroutine of water use in electrical industry, hopefully, the result of the forecast would possibly be improved.

In the commercial water use comparison, a system error seems to exist. All the forecasted levels are less than those in historical records, and each pair has a 12.8 to 16.2 percent forecast error. When deciding the values of EPCP and EPCI, it was found that the commercial water use in the past years increased too fast. One reason is, perhaps, the real commercial water use was underestimated at the beginning to justify taking commercial water use record separately. The new-established commercial water use category is more expensive than the residential water use that used to be put together with, so that under-estimated commercial water use might be reported by people who pay the bill. Another reason is that the economic reform has brought in market economy to China. Commercial activities are blossoming during recent years. Since it is at the turning point from the planned economy to market economy, the increased rate in commercial water use must be much higher than ever. After some years, the increase rate may slow down. Therefore, lower values were accepted in the simulation model in terms of a long-term forecasting.

There are no record of agricultural water use. Therefore it is not possible to make a similar evaluation of the model used for forecasting agricultural water use.

The strongest evaluation of the model and forecast, whether in support for or against it, may come from the comparison of the forecast with what really occurred. Nevertheless it will take a long time to prove a long-term forecast. In order to give a clear presentation of the forecasts, on which a simple eye evaluation could possibly be made, the results of a forecast selected by S_i (minimum) are presented in Figure 11.14 to Figure 11.19 for residential, industrial, agricultural, and commercial water use respectively.

Table 11-18 Comparisons between Forecasted and Actual Water Use

Years		1987	1988	1989	1990
Residential Water Use					
Actual	(10^4 m^3)	4789	5251	5393	5612
Forecasted	(10^4 m^3)	4971	5143	5317	5494
Forecast error	(%)	3.8	-2.1	-1.4	-2.1
Industrial Water Use					
Actual	(10^4 m^3)	23863	26147	23408	22197
Forecasted	(10^4 m^3)	23405	24070	24710	25370
Forecast error	(%)	-1.9	-7.9	5.6	14.2
Commercial Water Use					
Actual	(10^4 m^3)	1179	1319	1398	1538
Forecasted	(10^4 m^3)	996	1105	1219	1338
Forecast error	(%)	-15.5	-16.2	-12.8	-13.0

11.7 SUMMARY

In this chapter, future water demand by the residential, industrial, agricultural and commercial sector in Lanzhou urban area were forecasted by using the system dynamic model described in Chapter Ten. The parameters were estimated, or adopted from some relevant sources, according to the local situation. Alternative values were accepted for some of these parameters to reflect uncertainties. Year 1986 was chosen as the base year, from which water demand was projected into the future. The choice of 1986, rather than a more recent year as the base year, was for the consideration of having a comparison between the projected and the really occurred in order to evaluate the performance of the model. A range, rather than a single point value, has been obtained for the forecast of water use by each water use sector in each coming year.

The results reveal that water demand in Lanzhou urban area by all sectors, except agriculture, will continuously increase in the foreseeable future. On the average, the total urban water demand in Lanzhou will increase 42% in the year 2000, 85% in 2010, and about 144% in 2020.

The performance of the model in the case study shows that the model can produce reliable forecasts; and it can produce comparatively accurate forecasts when the parameters are estimated accurately. Therefore, care must be paid to determining the parameters and choosing alternatives for them, especially to those parameters which are very sensitive for causing changes in future water demand.

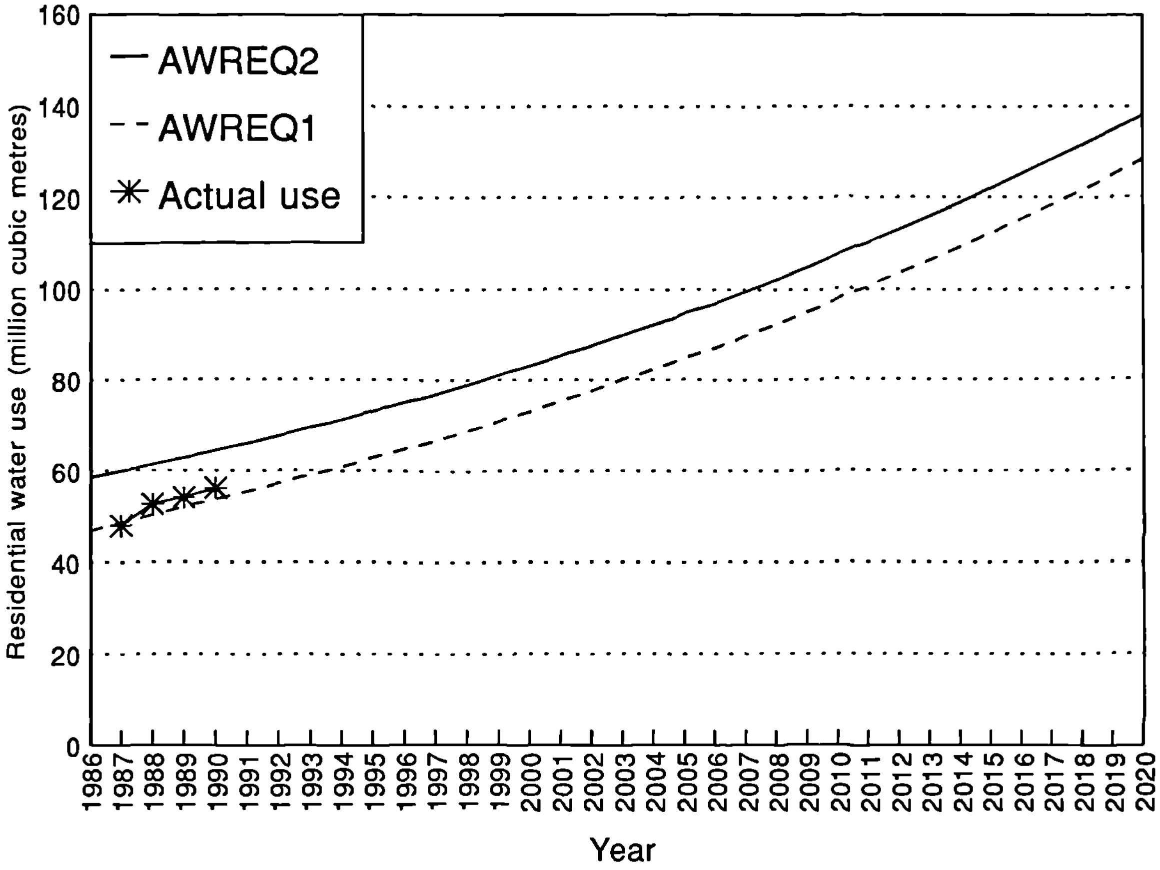


Figure 11.14 Residential water use forecast for Lanzhou

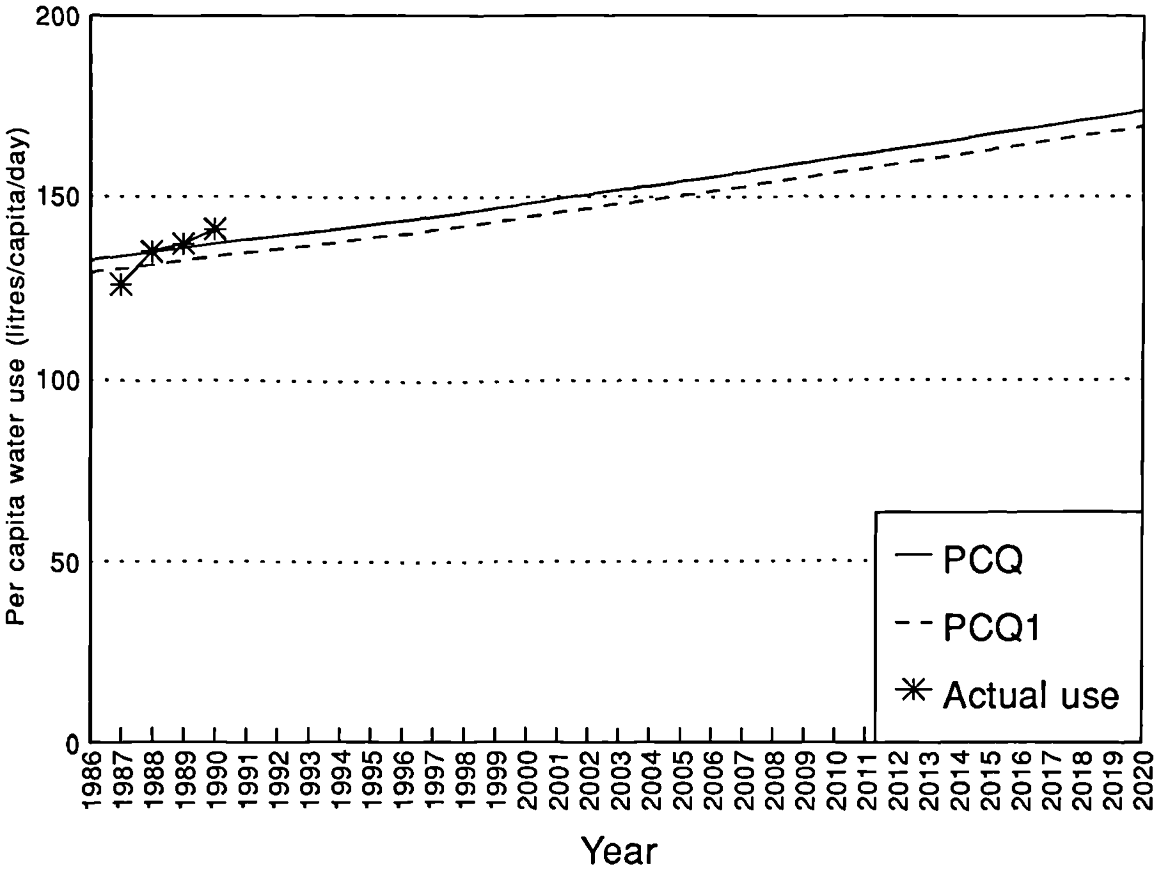


Figure 11.15 Per capita residential water use forecast for Lanzhou

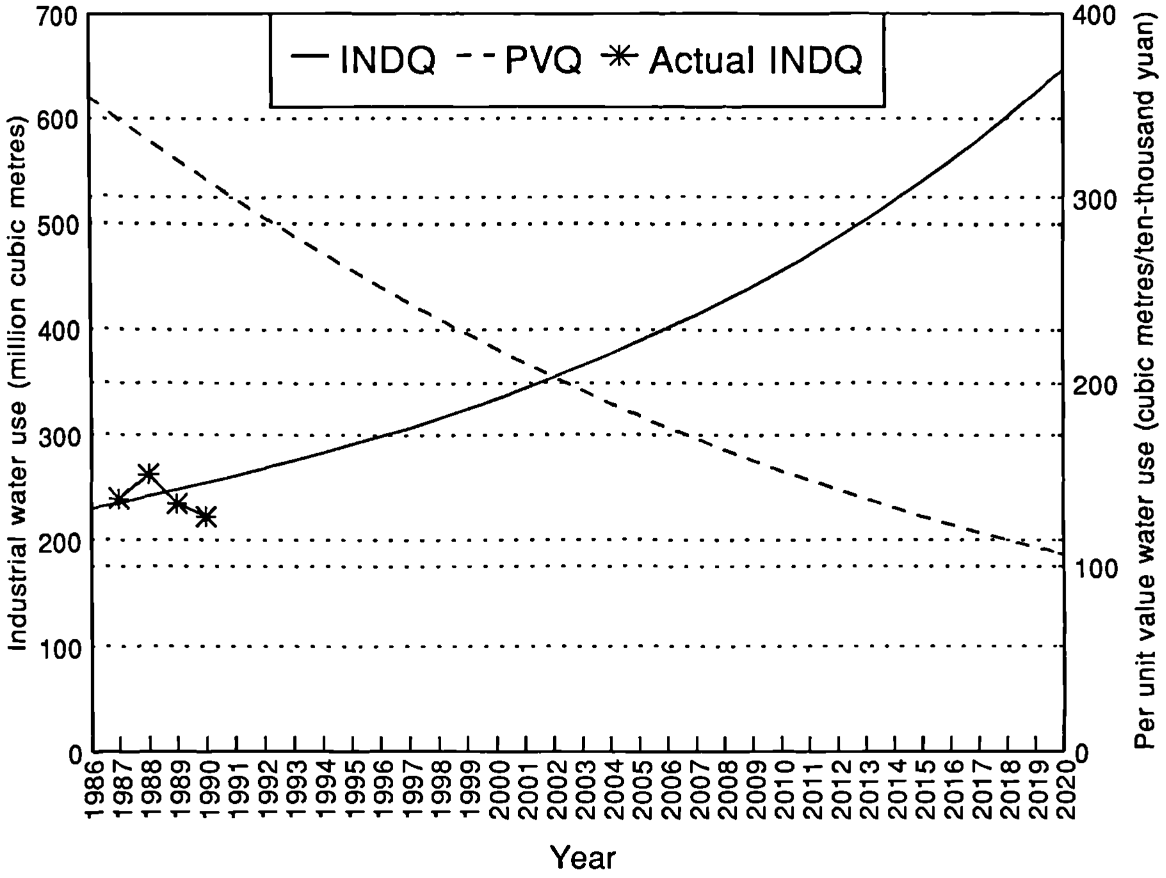


Figure 11.16 Total and per unit value industrial water use forecast for Lanzhou

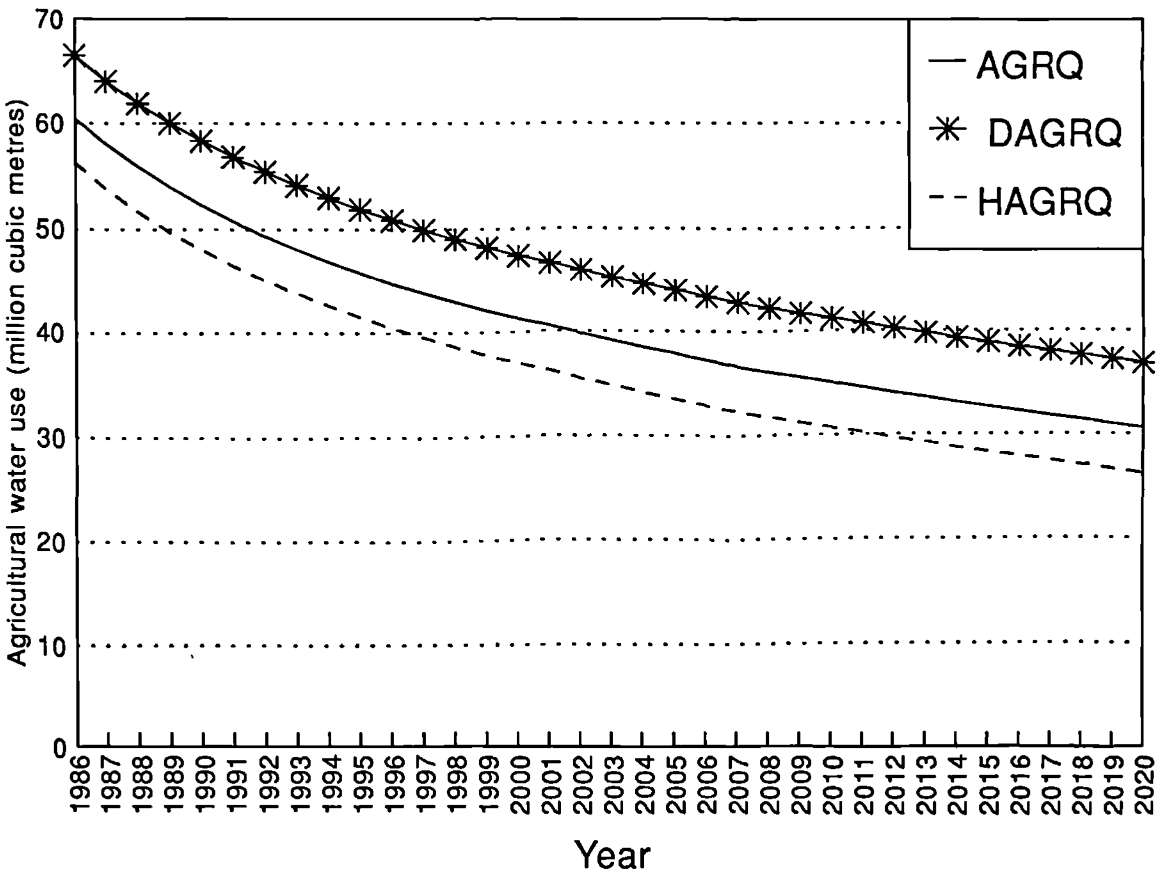


Figure 11.17 Agricultural water use forecast for Lanzhou

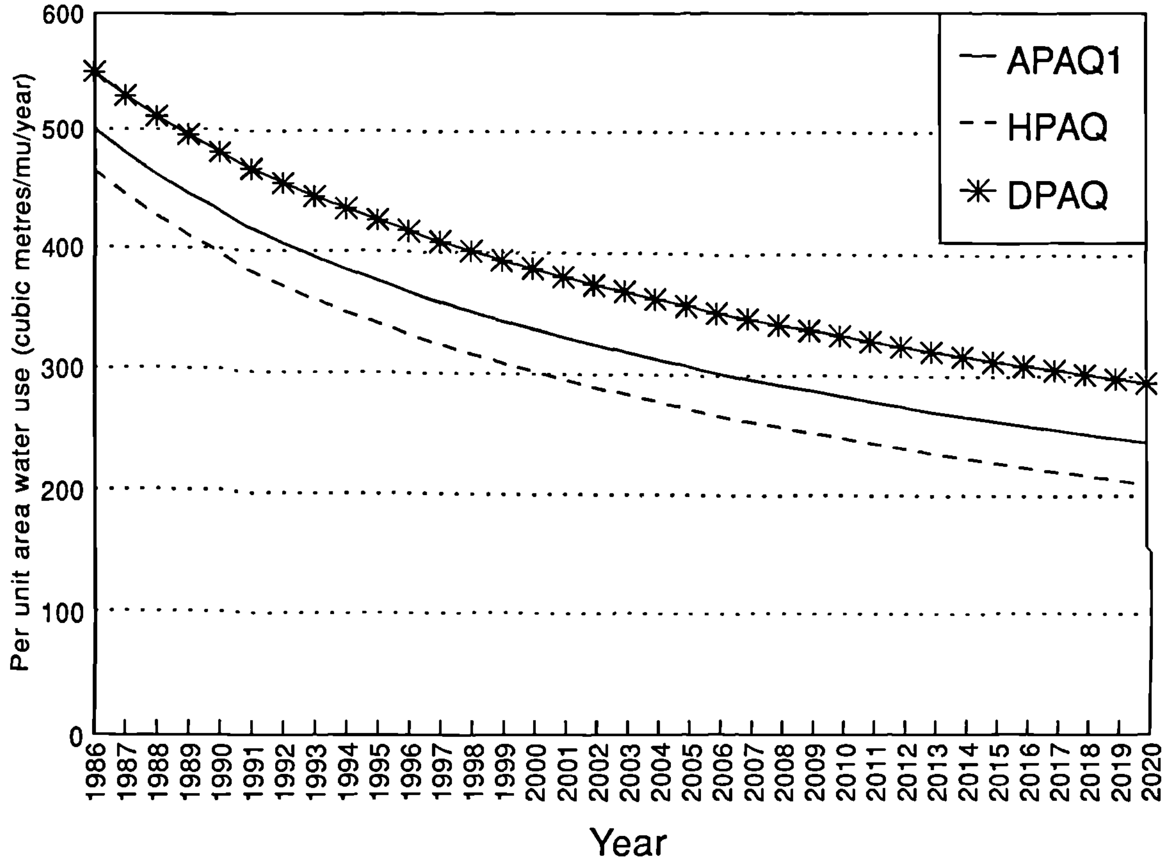


Figure 11.18 Per unit area agricultural water use forecast for Lanzhou

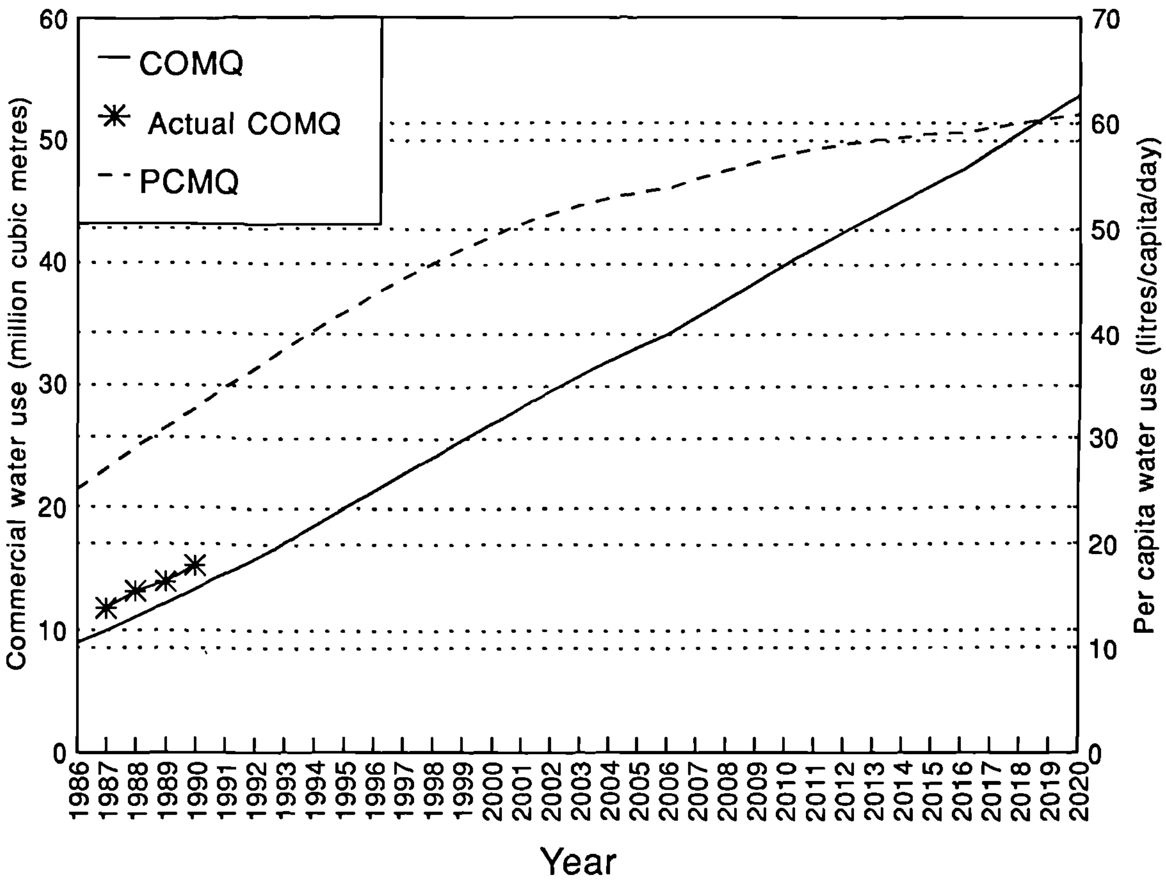


Figure 11.19 Total and per capita commercial water use forecast for Lanzhou

Chapter Twelve
CONCLUSION AND RECOMMENDATIONS

This research consists of two major parts of work: Chinese urban water demand system analysis, and model building for forecasting long-term urban water demand. The objective of the urban water demand system analysis is to identify the significant factors affecting water use, and the relationships between water use and these factors. The objective of the model building is obviously to build a forecast model, based on the relationships or patterns derived from the system analysis. The forecast model developed was applied in a case study, in which water demand in the urban area of Lanzhou was projected, and from which the model was evaluated. The significant contribution of this research, or the main conclusions derived from the above studies are presented in the following three sections.

12.1 FACTORS AFFECTING URBAN WATER USE

Analysing urban water demand is a very complicated subject since it is related to almost all aspects of urban activities. Water demanded by different sectors is influenced by different factors. Hence, it is preferable to disaggregate water use into groups or categories before doing analysis, if data permits this. In this study of Chinese urban water demand, water use is primarily disaggregated into four categories: residential, industrial, agricultural, and commercial water uses. Factors affecting urban water use were analysed based on these four sectors. The main findings derived from the analysis of the Chinese urban water use system are summarized below.

12.1.1 Effects of Factors (Aggregation and Obscurity)

From the regression analyses described in Chapter Four, it was revealed that the correlation between water use and some factors, such as population and income, change regularly with the level of data aggregate used (geographically), i.e. from national aggregate data to individual household data. A general trend is that the correlation coefficients (R squared) of the regression analyses decrease with data disaggregation. This was explained by the fact that aggregation obscures some of the effects of explanatory factors during the aggregation process. When data are aggregated, the differences and errors among the individual numbers aggregated together will be averaged out, and the effects of the factors that cause the differences will also be obscured. Conversely, when disaggregate data are used, the effects of factors that are obscured in the aggregate data will reappear. Therefore, without introducing new explanatory variables, the new pattern of water use (variance in the disaggregate data) cannot be adequately explained by the old explanatory variables that are significant in the aggregate analysis. So, the percentage of variation (R squared) of water use which can be explained by the old explanatory variables is reduced when more disaggregate data is used.

Based on this finding, it was further realized that different factors can play different roles in explaining water use patterns when various aggregate levels of data are used. Most data are available on a geographical scale. Some factors might appear to have more significant effects on water use, when spatial aggregate data are used in regression analysis, such as population and income in residential water use. Other factors may have more obvious effects at spatially disaggregate level analysis. In other words, the effects of some factors on water use are more easily obscured than other factors during the process of data aggregation along the spatial dimension. Therefore, factors affecting urban water use can be classified into groups according to their main influences at different scales. Factors that have obvious effects in an aggregate scale may be called 'macro factors', while factors that have clear effects in a disaggregate scale may be termed 'micro factors'. It is inappropriate to summarize which factors are important in influencing water use, without referring to the scale level. This theory can be used to explain the debates in the literature about which are the important variables influencing water demand, such as the argument raised by Murdock, et al. (1991).

The phenomenon of obscurity that occurs during the aggregation process can be utilized positively in determining the effect of factors. The effect of a specific factor on water use can be isolated under the assumption that other factors remain the same. The reality is that many factors are changing simultaneously. However, a similar situation can be created by aggregating data for the specific purpose of obscuring the effects of all the factors except the factor being analysed. This can be done by aggregating data along the dimension of the factor to be analysed. For example, the effect of income on residential water use may be isolated by dividing households into groups according to income only, like the data used in the national scale analysis. However, this needs a very large sample, or a large-size disaggregated data base to support it.

When the effects of factors are analysed, or the relationships between water use and the factors are estimated, these are then applied as relationships or patterns to forecast future water demand. Aggregation obscures the effects of the micro factors, and disaggregation reduces the strength of correlation between water use and the macro factors. Then, a question needing to answer is how this finding can be considered or reflected in forecasting.

A conclusion drawn by Dekay (1985) was that disaggregation results in the most accurate water demand forecasts. But can it be argued from this that the more disaggregate the data used, the more accurate the forecasts obtained? If the above theory of obscurity of effect is right, the answer must be 'no'. The endless disaggregation process will uncover the effects of more and more micro factors, which may not influence the long-term trend of water use but only short-time stochastic fluctuations. Most micro factors are subject to more uncertainties or stochastic fluctuation, and hence are difficult to predict as independent variables. This is not to say that disaggregation is not helpful to increasing the accuracy of forecasts. The main point is that disaggregation has its limitation in terms of both data availability and obscurity effects. Complete disaggregation will not result in the most accurate of forecasts. The relationship between the accuracy of forecasts and the level of disaggregation is described in Figure 12.1.

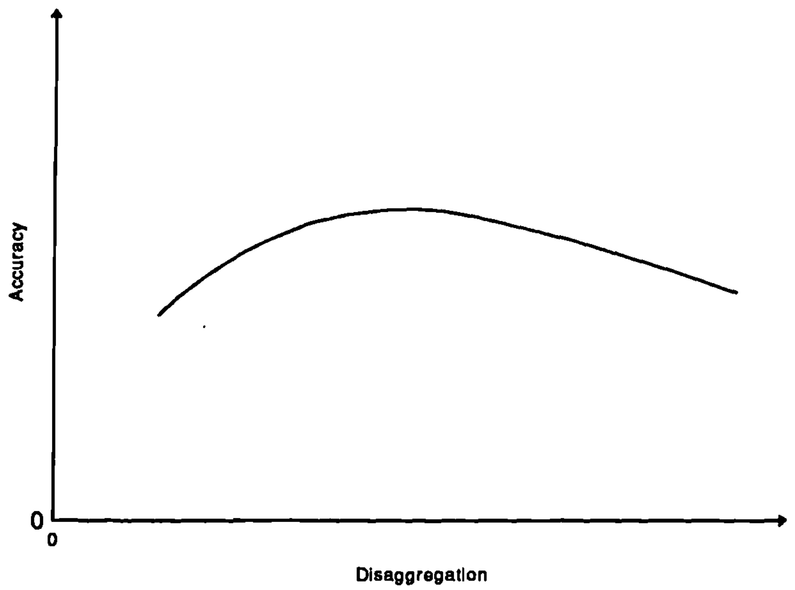


Figure 12.1 Disaggregation and Accuracy of Forecasts

In practice, the level of aggregation or disaggregation can only be decided by the purpose of the study, and how the study can proceed. Then, the major factors that need to be considered can be determined. For a long-term, urban scale, water demand forecast, although sectoral disaggregation to a certain level is necessary, more attention should be paid to the macro factors, like urban population, per capita income, industrial size, irrigated area, rather than those micro factors, such as the age of the head of household, number of days that the household is not in residence, and so on.

12.1.2 Factors Affecting Water Demand and Intensity

Among the factors affecting water use, a distinction has been made between factors affecting the demand for water and factors affecting water use intensity. The idea of making this distinction is germane to the per capita coefficient method, in which population is chosen as the only variable influencing water demand, and per capita water use is estimated to be a fixed value. However, apart from population, water use is also influenced by other factors or variables. If these factors are taken into account, it is clearer if they are directly related to per capita water use rather than total water use. Following this idea, the distinction is made between factors affecting the intensity of water use and factors affecting the demand for water.

For different water use sectors, various indicators may be chosen as explanatory variables affecting the demand for water. In general, they are indicators of the size or scale of the water using sectors. Even for one water use sector, different indicators may be chosen to indicate its size or scale, depending on data availability and reliability. For instance, value production and number of employees may be both acceptable as the indicator of industrial scale. However, different indicators of the scale or size of one sector are not normally acceptable in explaining water use simultaneously because of the problem of double counting. The size variables are regarded as factors affecting the demand for water, while the other factors are recognized as factors affecting water use intensity.

In this research, the variables recognized as those affecting water demand are: population for residential water use; gross productive value for industrial water use; irrigated area for agricultural water use; and population for commercial water use. Factors affecting the intensity of water use are such variables as per capita income, and family size, for residential water use.

The distinction between factors affecting the demand for water and factors affecting intensity of water use, is effective when factors are taken as explanatory variables in the causal relationships with water use. In practice, for a variety of reasons, some factors do not appear explicitly as variables relating to water uses; but their effects on water use are taken into account implicitly. Such examples include water conservation policy and technological improvement. It may be unnecessary to distinguish these factors specifically as to whether they affect water intensity or demand, since sometimes their effects are expressed in terms of total water use, and sometimes they are related to per unit water use, depending on custom or convenience. These factors may be called 'adjustment factors', from the role that they play. The water reuse rate in the industrial sector, and canal efficiency in the agricultural sector, are actually 'adjustment factors', because they are indicators of the effects of water reuse techniques, or water transfer facilities.

Although it is made subjectively, the above distinction between the factors affecting the demand for water and factors affecting water use intensity makes sense, and it also makes the relationships easier to understand. In the literature, although this kind of distinction has not been clearly stated, relating some variables to per unit water use has been widely adopted in water demand forecasting. However, the most important value of this distinction may be its contribution to the development of the forecasting model.

12.1.3 Significant Factors Influencing Urban Water Use

After analysing the Chinese urban water use system, factors that are considered significant in influencing the long-term future urban water demand in Chinese cities have been identified, as listed in Table 12-1.

These factors are definitely not the sole determinants of future water use. However, they are the most important factors responsible for the long-term change in water demand, compared to others. Factors not listed in the table are not necessarily unimportant in influencing urban water use. The reasons for omitting them are that they are micro factors, and they either only cause stochastic fluctuations in water use from an aggregate point of view, or they do not have a clear trend of change perspective from current to future time. In addition to the change element of water use (ΔQ), there is another element which contributes to or also comprises total future water demand (Q_t). This is the base year water use: Q_0 (see Chapter Nine). The base year water use may be partly explained by the effects of the factors unlisted in Table 12-1. These effects may also be compounded into the projection.

The choice of these listed factors is determined by the objective of long-term city-wide water demand study and forecasting. Under these conditions, more factors may be added to the list in Table 12-1, based on progress made in the factor-water-use-relationship analysis, especially if a specific city is being studied, since specific cities may have special characteristics which affect water use. Without an empirical investigation, no factor can be generally labelled as significant or insignificant in influencing urban water demand.

Table 12-1 The Significant Factors Suggested for Consideration in the Long-term Forecasting of Urban Water Use in China

For residential water use:

(1) numbers of urban population;
(2) average per capita annual income;
(3) average number of people in each urban family;
(4) water conservation policy.

For industrial water use:

(1) gross industrial productive value, or number of industrial employees;
(2) structure of urban industry;
(3) recycling of industrial water use;
(4) industrial technological improvements.

For agricultural water use:

(1) area irrigated;
(2) annually climatic fluctuation;
(3) irrigation methods;
(4) efficiency of canals.

For commercial water use (need to be further proved):

(1) numbers of urban population;
(2) average per capita annual income.

12.2 THE FORECASTING MODEL DEVELOPED

A survey in the literature shows that it is the first attempt to apply system dynamic simulation into long-term water demand forecasting. The concept of alternative futures was also applied in the simulation model by building in alternative values to the parameters and initial variables. The model developed is summarized in terms of its characteristics in Section 12.2.1 to 12.2.4, and concluded in 12.2.5.

12.2.1 Based on Causal Relationships

The four-step-procedure for answering the question of 'how much water will be demanded at some time in the future' has indicated that a key issue in water demand forecasting is to find out the effects of the factors affecting water use.

This supports the hypothesis that building up the causal relationships between water use and explanatory variables is the basis of water demand forecasting. The causal relationships are, and can only be, established through historical data analysis.

In terms of causal relationships, many forecasting methods that have been mentioned in the Literature Review may be labelled as based on causal or structural relationships, such as the single coefficient methods, multiple coefficient methods, econometric or requirement models. An important point employed in the system dynamic model is that the 'changes' in the factors cause the 'change' in water use. In other words, it tries to forecast the quantity of water increased or decreased compared with the base year, rather than to forecast water use directly. Only factors that have clear trends related to variables instrumental in changes in water demand are considered; factors that do not have clear trends, or change stochasticly, are ignored during the forecasting process. The change in water use is just seen from a long-term perspective. The short-term fluctuation of water use caused by some micro factors, such as the daily, weekly, or even seasonal water use fluctuations, should not be the vehicle implicit in long-term forecasting. The emphasis in the research is on the long-term trend of urban water use, and the factors that cause this trend.

Focusing on the 'change' in water demand forecasting may be unduly influenced by the base year values. If water use in the chosen base year is not normal, but 'biased', then the resulting forecasts may be biased. Therefore, in choosing the base year, the relevant criteria are data availability, representativeness, and as current a year as possible. When uncertainty is involved, values in different years, or averages, may be used to produce alternative futures.

The causal relationships built into the model are based on the distinction between the factors affecting the demand for water and the factors affecting water use intensity. Only the explanatory variables indicating the size of the water use sectors are related to the total water used by that sector. Other explanatory variables considered are related to per unit water use; or changes in those variables contributing directly to the change in per unit water use.

12.2.2 Dynamics

Since major attention is paid to the 'change', either in water use or in the factors affecting water demand or intensity, a time variable can be easily introduced into the causal-relationships, as described in Chapter Nine, so that dynamic characteristics can be attached to the model. The introduction of the time variable in describing the changing processes of those factors or explanatory variables also provides the basis for using the procedures of System Dynamic simulation. This enables the forecasting results to be really time-related. The processes of 'changes' in water use and in those factors are clearly stated in the simulation model.

12.2.3 Considering Alternative Futures

> "Simulation is not an optimizing technique. Rather it is a formal way of systematically asking and answering the question, 'what happens if this is done?'" (Meta Systems Inc., 1975).

As defined at the beginning, forecasts are conditional statements about the future. For long-term water demand forecasting, many uncertainties are involved, due to the various assumptions upon which forecasts are made. Therefore, it is highly desirable to present the assumptions explicitly and to give the corresponding answers to 'what happens if this is done?'.

The simulation model developed can perform this function easily and explicitly. By issuing different values to the parameters and initial variables, alternative forecasts, or scenarios, can be obtained. If no priority is given to one particular alternative future obtained, a probability distribution of the alternative futures can show a picture of whole outcomes based on various assumptions, which might be thought to be a more scientific way than a single forecast presentation. The alternative values issued for parameters, and initial variables which are presented in tables, can supply more information for planners and decision-makers when they use the forecasts or the model. However, care must be taken in choosing and combining alternative values for the parameters in order to avoid misleading results.

12.2.4 Explicit

As repeated previously, explicit statements about the assumptions upon which long-term forecasts are based are extremely desirable, especially in convincing decision-makers to accept the forecast and consider it as an input in their decision-making process. Forecasts are useless unless employed in improving planning and decision making (Makridakis and Wheelwright, 1989, p421).

The simulation model developed has the obvious characteristic of being explicit. The step-by-step procedures used in the system dynamic simulation, in which the relationships and the changing processes of the factors concerned are described, is comparatively easy to understand. In addition, the alternative assumptions, which are expressed as different values of parameters or initial variables, are clearly presented by tables. Except for a few specific parameters indicating the relationships between water use and the factors, most of them are easily understood by non-professional people. Thus, decision-makers can even make their own choices for some parameters when they use the model. Hence it can be an extremely friendly tool in the decision-making process.

12.2.5 Conclusion

For long-term forecasting, all the above characteristics, i.e explicit, dynamic, based on casual relationships, and considering alternative futures, are desirable.

Thus, the system dynamic simulation model developed in this research satisfies these conditions, and as such it is regarded as a satisfactory model.

In practice, the most crucial criterion in evaluating a forecasting model is whether it produces accurate forecasts. When building the model, an attempt was made to incorporate all the significant factors revealed in the system analysis based on causal relationships. This should be, to a certain extent, a kind of guarantee for the reliability of the forecasts produced from it, but not a guarantee of accuracy. Inaccurate forecasts can result from another source rather than the model employed, i.e. the estimation of the parameters, including coefficients, elasticities, and change rates of the exogenous factors. From Chapter Ten, it can be seen that all the parameters and initial variables in the model are left to be determined. Determining the parameters is something closely related to the local situation, i.e. the city being studied. The accuracy of the forecast produced from the model greatly depends on the accuracy of the values estimated for the parameters. A principle suggested in the text is that the greater the knowledge about local water use, the more accurate the forecast will be. It can be concluded, from this perspective, that no model can be guaranteed to produce accurate forecasts on a hundred percent of occasions.

12.3 THE CASE STUDY

Although no model can guarantee to produce accurate forecasts, when a model is applied in practice or in a case study, it is essential to make the forecast as accurate as possible, and as reliable as possible. The accuracy of a forecast greatly depends on the accuracy of the values estimated for the parameters, including coefficients, elasticities, etc. The application of the system dynamic simulation model is actually a process to determine the values of the parameters, and to select a base year. When all the parameters are determined, the model can be run to produce forecasts. Alternative futures can be forecasted from alternative values estimated for the parameters, to reflect the uncertainties involved.

After a comprehensive investigation of urban water use and its social and economic environment in Lanzhou, the parameters in the system dynamic simulation model were determined, and some of them were estimated with alternative values. Thus a range, rather than a point value was projected for water demand in Lanzhou for residential, industrial, agricultural, and commercial sectors separately, and for each future year. The forecast result shows that, except for the agricultural sector, water demand by all the other sectors will grow in the foreseeable future. Taking 2010, for example, compared with 1986, residential water demand is projected to increase between 65% to 178%; industrial water use to increase 75% to 132%; commercial water use to increase 163% to 612%; agricultural water use to decrease 32% to 57%. On an average, total urban water demand in Lanzhou is projected to increase 85% in 2010, compared with 1986.

Statistical analysis on the forecast results reveals that both the standard error and forecast range increase with the horizon of forecast. The longer the horizon, the bigger the error, and the wider the range. This can be explained by the fact that the further the forecast into the future, the greater is the uncertainty. Sensitivity analysis shows that future water demand is more sensitive to errors in some parameters than in others. These parameters are mostly related to the factors that significantly influence water demand and change dramatically into the future. After a comparison between the projected demand from the model and the demand which actually occurred from 1987 to 1990, comparatively, very accurate forecasts were produced, especially for the residential water use sector. From the perspective of the model structure and the relationships employed, it can be concluded that the model produces reliable forecasts. When the parameters are estimated accurately, it will produce accurate forecasts as well.

12.4 SOME REFLECTIONS ON THE STUDY

Although two trips were made to China during the process of this research for data collection and field investigation, supplemented with contributions from personal and official sources, serious restrictions on availability and limitations on data still exist. This constraint is responsible for the structure and content of this study, and could not be avoided.

From Part I, it can be seen that the research is still a long way from establishing the effects of all the factors that influence water use. For this reason, the system dynamic simulation model developed has taken relatively fewer factors into account, and the effects of some factors are just simply estimated or assumed.

It can also be appreciated that major attention has only been paid to water demand and the factors affecting it. The simulation model has not taken the profile of water supply fully into account as a basic component of the urban water use system. The model has not really considered the fact that a dynamic mechanism exists to balance water demand and water supply, in which water supply can influence the factors affecting water use. In particular, when water supply fails to meet the needs of water demand, it will influence and restrict those factors affecting water use. The feedback effect of water supply on the factors affecting water use has not been explicitly considered in the model of water demand forecasting. This may be seen as a shortcoming of the simulation model, particularly from the perspective of systematic dynamics.

The major objective of this research is forecasting water demand, which is an input in water resources planning and management. Influencing water using sectors through water supply could be regarded as part of work of water resources planning. From this point of view, it may be argued that not having completely considered the feedback effect of water supply, is acceptable at this stage, since this study is of water demand forecasting, not water supply planning. In fact, when water conservation policy and technological improvement towards reducing water use were assessed, the feedback effect of water supply was partly considered, albeit implicitly. Furthermore, the system dynamic simulation model can produce alternative forecasts based on various assumptions. If the relationships between water supply and some factors can be decided, there would be no problem in combining these relationships into the model. These relationships may be determined through the measures of planning, like population growth control, industrial development control, etc.

Another limitation may be the omission or neglect of the peak demand for water in this research. In engineering, it is an important issue, because project design requires an assessment of how much storage is needed in the system to cater for diurnal variations so that sources can run at a fairly constant output (Bland, 1986). Factors that cause the short-term, i.e. daily, weekly, and seasonal fluctuations are mostly responsible for the peak demand. Unfortunately, these factors have been almost entirely omitted or neglected in this long-term forecasting study, for the reason declared before. Moreover, it could be suggested that peak demand is a totally different research subject, quite separate from this research.

12.5 RECOMMENDATIONS

Given the limitations of the present study, several recommendations can be made with regard to future research.

(1) The first is the need to improve data availability. Data on urban water use should be recorded according to sectors in the Chinese city's statistics.

Commercial water use should be separated from the residential water use category. Agricultural water use should also be included in the statistics, even estimated data if actual data are not directly available. If possible, a city-wide, or even nation-wide data base on water use should be established in order to provide detailed and systematic information about water use in China.

(2) Further research should be undertaken on the relationship between water use and factors affecting use, along with the improvement in data availability. According to the findings of this research, the effect of each individual factor on water use can be revealed theoretically by obscuring the effects of other factors through data aggregation. The effects of some factors can also be revealed by devoting effort to experimental research, such as on irrigation methods and water use, industrial technological improvement and water use, water saving facilities and residential water use, etc. In China, the relationship between water demand and water price has not been studied at all. Therefore attention should be paid to this field, especially from the perspective of the development of urban infrastructure, as a result of introducing a market economy.

(3) In water demand forecasting, further research can be done by considering more factors in the simulation model. This would be possible based on further research on the relationships between water use and the explanatory factors. And, it would also be desirable to develop the model towards a complete system dynamic model, which takes the feedback effects of water supply into account.

(4) The forecasting model developed deliberately serves as a city-wide approach to the management of water resources in Chinese cities. The determination of the parameters and initial variables depends greatly on the situation in each city under investigation, and these can be quite different from city to city. Therefore, it is recommended that this model, or the structure and

the general idea behind it, be used to forecast water demand for cities in China by those who are intimately familiar with the local water use situation.

APPENDIX

APPENDIX A: THE DEDUCTION OF ELASTICITY

Elasticity, whether price elasticity, income elasticity, or in terms of other independent variables, is defined by the following general equation:

$$E = (dD/dI)\ (I/D) \qquad \text{(A.1)}$$

where E is elasticity, D is the dependent variable, and I is the independent variable.

Suppose a logarithmic relationship exists between D and I, like:

$$Ln(D) = b + aLn(I) \qquad \text{(A.2)}$$

where b is the constant term and a is the slope.

In the income elasticity analysis undertaken in Chapter 4, the slope "a" is regarded as the elasticity "E". The deductive process is presented as follows.

Let $$Y = Ln(D) = b + aLn(I) \qquad \text{(A.3)}$$

then $$dY/dI = a/I \qquad \text{(A.4)}$$

and $$dY/dD = 1/D \qquad \text{(A.5)}$$

from Equation A.5, we can obtain

$$dY = dD/D \qquad \text{(A.6)}$$

let dD/D replace dY in Equation A.4, it becomes,

$$(dD/D)/dI = a/I \qquad \text{(A.7)}$$

That is $$(dD/dI)\ (I/D) = a \qquad \text{(A.8)}$$

So $$E = (dD/dI)\ (I/D) = a \qquad \text{(A.9)}$$

Therefore, the slope of "a" can be regarded as the elasticity. It will not influence the result of the deduction whether the base of the logarithmic equation is at "e", or "ten".

APPENDIX B: DATA USED IN THE REGRESSION ANALYSES

B.1 Data Used in the Inter-city Scale Analysis

Table B-1 Water Supply and Social Economic Situation in Chinese Cities in 1985

No.	City Name	(1)	(2)	(3)	(4)	(5)	(6)*
01	Beijing	43968	25999	463.3	153.7	2916363	907.80
02	Tianjin	37389	15774	400.0	108.0	2774500	811.80
03	Shijiazhuang	11105	6721	82.0	224.5	547068	752.00
04	Taiyuan	12676	5175	126.0	112.5	587774	580.08
05	Huhhot	6550	3440	40.2	234.4	142163	669.00
06	Shenyang	35557	15621	248.0	172.5	1518046	721.00
07	Dalian	10290	3409	135.2	69.1		784.00
08	Changchun	10939	5288	125.2	115.7	580678	617.80
09	Harbin	12029	6273	174.5	98.5	787223	712.00
10	Shanghai	115406	41302	687.1	164.7	6532148	1012.00
11	Nanjing	26236	12370	184.6	183.6	1052012	772.00
12	Hangzhou	17484	8144	100.2	222.7	814765	827.28
13	Hefei	9242	4291	58.9	199.6	296685	631.00
14	Fuzhou	12036	6553	77.4	232.0	318085	752.00
15	Nanchang	16901	6558	89.1	201.7	345562	557.71
16	Jinan	15794	6464	116.0	152.7	586857	731.64
17	Zhengzhou	17398	6212	90.4	188.3	404815	608.00
18	Wuhan	54334	25486	280.6	248.8	1451872	726.96
19	Changsha	16523	9859	115.7	233.5	324520	690.05
20	Guangzhou	62470	34995	257.0	373.1	1437820	1046.52
21	Nanning	15846	7226	55.2	358.6	183548	683.40
22	Chengdu	19471	6447	132.6	133.2	761722	644.04
23	Chongqing	16194	7219	159.9	123.7		762.36
24	Guiyang	9204	3564	75.0	130.2	293641	614.11
25	Kunming	8226	4227	98.8	117.2	454829	1144.00
26	Lhasa	282	278	3.5	217.6	1712	
27	Xian	19330	7295	156.0	128.1	683152	718.61
28	Lanzhou	26660	6351	97.1	179.2	581693	640.90
29	Xining	5577	1955	48.0	111.6	111776	853.72
30	Yinchuan	1398	853	21.0	111.3	66828	717.48
31	Urumuqi	3460	2419	74.1	89.4	237488	756.00

Source: The State Statistical Bureau of China, 1985a, 1985b.

Note: (1): total amount of water supplied, in ten-thousand cubic metres; (2): residential water use, in ten-thousand cubic metres; (3): number of population served, in ten-thousand people; (4): per capita daily water use, in litres per capita per day; (5): gross industrial value product, in ten-thousand Chinese yuan; (6): per capita annual income, in yuan per capita.

Table B-2 Water Supply and Social Economic Situation in Chinese Cities in 1986

No.*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)*
01	243.1	87639	27159	38901	451.0	165.2	2958343	1067.40
02	152.5	48520	19426	26684	423.6	125.6	3065122	988.44
03	160.4	31840	6739	21968	106.0	164.9	632100	766.50
04	66.0	22586	5934	16203	135.0	120.4	660548	657.28
05	29.8	9590	4997	4078	52.0	263.3	158390	848.88
06	165.0	51240	21074	26507	299.5	192.8	1782693	887.40
07	43.3	14791	4245	8183	156.5	74.3		910.80
08	36.0	12001	5835	4718	182.0	87.8	608350	831.00
09	69.0	20602	8806	10338	223.8	107.8	876144	825.04
10	627.7	191833	45723	133653	710.3	176.4	6777450	1214.76
11	203.5	69001	15499	49586	208.0	204.1	1129322	930.40
12	65.9	23967	9403	13876	110.5	233.1	931695	1012.00
13	55.7	12426	5699	6279	65.4	238.7	336837	750.00
14	69.4	24028	8114	13529	106.3	209.1	376235	847.08
15	52.3	17494	6827	9902	110.0	170.0	386774	685.74
16	74.5	25876	7431	17188	129.0	157.8	684430	888.12
17	62.0	23648	8207	13580	108.0	208.2	446176	798.00
18	225.4	70842	33998	32635	328.6	283.5	1556583	898.00
19	44.0	18219	9912	7662	116.0	234.1	383236	795.00
20	378.7	101780	38383	58631	299.1	351.6	1530174	1230.12
21	44.6	17907	10053	6311	60.1	458.4	198752	851.00
22	88.0	31410	7639	20835	150.9	138.7	797096	785.88
23	107.4	28384	10124	14234	222.1	124.9		910.00
24	30.8	10040	3918	3803	78.0	137.6	316857	742.00
25	26.0	9709	4969	3659	111.0	122.6	469958	946.00
26	3.0	360	345	0	9.0	105.0	4690	
27	88.0	29513	11587	19530	172.0	184.6	765938	910.68
28	127.0	31388	5574	24576	114.2	133.7	580456	776.00
29	26.4	10203	2556	7367	57.0	122.9	123511	929.16
30	15.0	5288	1038	4027	32.0	88.9	77881	766.00
31	20.9	6830	4089	2672	92.0	121.8	261446	843.00

Source: The State Statistical Bureau of China, 1986a, 1986b.

Note: The name of the cities are the same as those listed in Table B-1, corresponding to the number.

Note: **(1)**: total water supply capacity, in ten-thousand cubic metres; **(2)**: total amount of water supplied, in ten-thousand cubic metres; **(3)**: residential water use, in ten-thousand cubic metres; **(4)**: **Industrial** water use, in ten-thousand cubic metres; **(5)**: number of population served, in ten-thousand people; **(6)**: per capita daily water use, in litres per capita per day; **(7)** gross industrial value product, in ten-thousand Chinese yuan; **(8)** per capita annual income, in yuan per capita.

Table B-3 Water Supply and Social Economic Situation in Chinese Cities in 1987

No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
01	317.5	61996	31212	25121	513.9	166.4	3277303	1182.00
02	175.7	54924	22175	29375	430.7	141.1	3082062	1094.64
03	148.0	32954	6633	22702	109.0	159.1	677739	726.00
04	66.7	23598	6134	16991	139.0	120.9	682825	1485.00
05	29.1	8872	4385	4010	53.8	223.3	178077	804.00
06	173.5	51961	22614	25808	317.7	195.0	1796674	975.60
07	42.5	15539	4093	8441	158.0	71.0		1076.94
08	36.0	12604	6350	4680	146.2	119.0	744954	901.00
09	75.0	25774	12272	12399	245.0	137.2	971634	878.16
10	720.4	214974	51360	150864	753.2	186.8	6849690	1347.02
11	227.5	75633	17155	51001	218.0	215.6	1289412	1493.00
12	190.0	33879	9678	23287	113.5	233.6	944517	1122.00
13	58.2	12925	4046	8417	69.4	159.7	391903	842.94
14	70.1	21277	8794	10165	102.4	235.3	438613	985.00
15	127.4	41487	7344	33044	112.0	179.6	405843	748.68
16	76.0	25562	7084	16708	126.0	154.0	777190	996.94
17	66.0	23646	7435	14149	112.0	181.9	480855	943.20
18	224.1	69605	34220	31013	317.6	295.2	1658869	982.80
19	48.2	20244	11901	6283	122.0	267.3	421435	887.76
20	439.1	113752	42184	68794	306.0	377.7	1752604	1415.40
21	45.6	19357	9414	6878	70.6	365.3	224468	899.00
22	95.1	31143	7979	20400	148.5	147.2	837701	869.23
23	115.4	28749	10754	15530	232.0	127.0		1031.00
24	34.3	8880	4505	2568	84.0	146.9	344593	996.00
25	27.0	9864	4315	4866	113.0	104.6	521746	1032.60
26	1.5	365	345	15	5.0	189.0	5538	
27	84.5	31573	10497	16343	245.0	117.4	835115	1034.48
28	127.0	33020	4839	26734	105.5	125.7	620038	870.50
29	36.6	11439	2917	8222	62.3	128.3	135588	1030.00
30	13.4	4030	1525	2225	37.8	110.5	88499	854.88
31	20.9	6718	4335	2282	98.0	121.2	291260	1105.96

Source: The State Statistical Bureau of China, 1987a, 1987b.

Note: The name of the cities are the same as those listed in Table B-1, corresponding to the number.

Note: **(1)**: total water supply capacity, in ten-thousand cubic metres; **(2)**: total amount of water supplied, in ten-thousand cubic metres; **(3)**: residential water use, in ten-thousand cubic metres; **(4)**: **Industrial** water use, in ten-thousand cubic metres; **(5)**: number of population served, in ten-thousand people; **(6)**: per capita daily water use, in litres per capita per day; **(7)** gross industrial value product, in ten-thousand Chinese yuan; **(8)** per capita annual income, in yuan per capita.

Table B-4 Water Supply and Social Economic Situation in Chinese Cities in 1988

No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
01	268.1	84451	44496	33374	491.3	248.1	3727300
02	212.0	71473	27627	40026	552.5	137.0	3363000
03	155.5	34045	6646	23254	116.6	156.2	859000
04	66.7	23473	7059	15839	157.6	122.7	748100
05	23.5	9462	4895	4187	56.4	237.8	208700
06	184.4	53701	23447	26739	318.3	201.8	1950800
07	42.5	17789	5399	9052	164.6	89.6	
08	50.1	14460	7474	5602	165.0	124.1	873700
09	75.1	46667	12102	13376	246.4	134.6	1124400
10	929.5	235197	56440	167474	755.7	204.6	7003300
11	247.5	86926	19386	60958	227.0	234.0	1489500
12	197.3	36304	9974	24818	115.0	237.6	1039900
13	65.7	14022	4541	8843	71.4	174.2	478700
14	79.5	23745	9827	11589	108.6	247.9	574200
15	74.7	26336	8571	16507	119.4	196.7	451600
16	85.5	27912	7963	18587	135.0	161.6	931900
17	65.7	23480	6960	15592	115.4	165.2	535200
18	241.8	77278	38443	33624	337.3	312.3	1822400
19	49.0	22737	10491	10216	123.0	233.7	479000
20	614.6	201222	45351	154499	310.1	400.8	2196700
21	57.0	21579	9809	7961	80.8	332.6	257400
22	112.2	36255	11345	22742	158.5	196.1	990000
23	115.4	30878	10786	17202	229.3	128.9	
24	66.9	21155	6002	12239	94.6	173.8	382600
25	29.0	10021	5369	4088	108.2	99.1	598300
26	4.3	1570	948	506	12.3	211.2	6000
27	82.0	31024	10402	16223	250.0	114.0	955600
28	127.0	32462	5287	26500	122.0	118.7	685800
29	34.4	11451	2924	7968	62.5	128.2	147100
30	24.1	5663	1861	3179	41.0	124.3	109700
31	23.5	8319	5229	3048	98.2	145.9	347600

Source: The State Statistical Bureau of China, 1988a, 1988b.

Note: The name of the cities are the same as those listed in Table B-1, corresponding to the number.

Note: **(1):** total water supply capacity, in ten-thousand cubic metres; **(2):** total amount of water supplied, in ten-thousand cubic metres; **(3):** residential water use, in ten-thousand cubic metres; **(4): Industrial** water use, in ten-thousand cubic metres; **(5):** number of population served, in ten-thousand people; **(6):** per capita daily water use, in litres per capita per day; **(7)** gross industrial value product, in ten-thousand Chinese yuan.

Table B-5 Water Supply and Social Economic Situation in Chinese Cities 1989-1991

No.	(1)	(2)	(3)	(4)	(5)	(6)
01	282.9	82702	44772	32110	509.7	240.6
02	188.9	65810	26647	35769	569.7	129.0
03	155.2	32515	6112	20681	118.2	141.6
04	64.6	21772	6834	14237	201.3	93.0
05	24.0	10066	4415	5159	57.0	212.2
06	180.5	54519	24993	25389	324.7	210.9
07	52.0	18631	6117	8958	173.4	96.6
08	50.1	16041	8844	6033	166.2	145.8
09	75.0	26715	12903	13236	252.0	140.3
10	885.6	229801	60103	156066	777.8	211.8
11	309.0	94553	19204	68345	232.0	226.8
12	199.7	33644	12121	19779	118.8	279.5
13	65.7	15196	4276	10092	81.1	144.4
14	85.0	27238	10942	13696	118.9	252.1
15	79.9	27133	8917	17057	129.6	188.5
16	92.8	27730	8229	17662	137.0	164.5
17	65.7	24037	7864	15132	115.0	187.3
18	266.0	81297	40508	35250	338.8	327.5
19	49.0	24588	11828	11393	123.0	263.4
20	670.5	194976	51190	142662	322.1	435.4
21	68.5	24133	9439	13034	85.4	302.8
22	131.0	39063	12543	24116	165.7	207.4
23	115.4	31651	10776	17402	229.3	128.7
24	73.1	13403	6384	4678	104.0	168.2
25	29.0	10425	4503	5620	117.5	105.0
26	1.5	547	300	10	6.0	136.9
27	93.0	32547	10289	17450	247.0	114.1
28	127.0	36829	6755	29277	123.7	149.6
29	34.4	12164	3026	7554	62.9	131.8
30	25.1	6289	2127	3322	42.3	137.7
31	24.0	8513	5145	3263	99.0	142.3
01	285.6	84771	46777	30573	512.5	250.1
02	199.1	63203	24566	34104	572.6	117.5
03	158.1	33400	7706	21206	139.0	151.9
04	71.0	23731	7151	15759	174.2	112.5
05	27.9	10048	4700	4806	59.3	217.1
06	185.2	55670	25395	25363	324.7	214.3
07	58.5	20826	6998	9841	174.2	110.1
08	48.1	17374	9883	6274	174.2	155.4
09	80.0	26640	13555	11784	255.6	145.3
10	967.1	257040	66504	177394	811.7	224.5
11	325.0	102038	20879	76167	235.6	243.0
12	101.7	34945	13481	18445	123.0	300.0
13	65.7	16117	4748	10501	83.9	155.0
14	75.0	25128	11308	11095	119.5	259.3
15	81.7	27292	9378	17186	129.7	198.1
16	98.3	26438	7448	17588	137.0	148.9
17	65.7	24217	8201	14836	136.4	164.7
18	276.7	84736	41543	37177	357.6	318.3

to be continued

No.	(1)	(2)	(3)	(4)	(5)	(6)
19	64.0	25995	12465	11933	125.0	273.2
20	795.5	236421	54791	144968	330.6	454.1
21	68.6	24515	9707	12744	87.4	304.3
22	149.0	40962	13874	24489	172.3	220.6
23	116.4	32853	10516	18441	230.4	125.0
24	79.3	14289	6911	4937	112.7	168.0
25	49.0	11162	5094	5785	130.0	107.4
26	6.8	1570	506	1044	12.3	112.7
27	96.7	34824	15244	17864	256.3	163.0
28	146.0	35976	7558	27481	127.0	163.0
29	34.4	12274	3225	8216	63.7	138.7
30	26.3	7407	2405	4474	42.8	153.9
31	27.0	9144	5564	3480	102.5	148.7
01	412.1	88886	51219	30577	522.0	268.8
02	212.1	62518	23868	34873	514.0	127.2
03	159.9	34143	8089	19111	142.0	156.1
04	84.3	28092	7331	19904	167.3	120.1
05	28.7	9990	4674	4922	61.4	208.6
06	191.6	57214	24487	27925	346.0	193.9
07	65.0	23078	8110	10925	203.2	109.3
08	50.6	18494	10792	6588	170.3	173.6
09	87.5	28140	14455	12379	261.5	151.4
10	750.9	310025	156108	139509	801.3	533.7
11	333.0	108416	21389	82842	240.0	244.2
12	101.8	33672	13712	19833	125.0	300.5
13	84.3	16640	5745	9901	84.2	186.9
14	73.5	26618	12247	11510	120.4	278.7
15	81.7	28105	10938	15645	125.4	239.0
16	109.0	27864	7776	18311	139.0	153.3
17	74.0	27721	8027	18543	142.4	154.4
18	298.9	87835	36138	35716	361.7	273.7
19	64.0	27525	13109	12479	125.0	287.3
20	818.4	265173	57371	204425	340.3	461.9
21	68.6	24980	11688	11746	79.9	400.8
22	143.7	38307	13493	22521	171.7	215.3
23	118.4	33937	10980	19040	231.9	129.7
24	90.3	32440	8087	18651	116.7	189.9
25	43.0	13055	5924	6031	130.0	124.8
26	6.8	1380	459	500	13.3	94.6
27	87.8	35039	11243	18593	250.1	123.2
28	146.0	37777	7169	29939	131.0	149.9
29	34.4	12619	3287	8474	64.7	139.2
30	27.5	7650	2644	4603	44.8	161.7
31	29.0	10341	6617	3601	105.0	172.7

Source: The State Statistical Bureau of China, 1989a, 1990a. 1991a.

Note: The name of the cities are the same as those listed in Table B-1, corresponding to the number.

Note: **(1):** total water supply capacity, in ten-thousand cubic metres; **(2):** total amount of water supplied, in ten-thousand cubic metres; **(3):** residential water use, in ten-thousand cubic metres; **(4): Industrial** water use, in ten-thousand cubic metres; **(5):** number of population served, in ten-thousand people; (6): per capita daily water use, in litres per capita per day.

B.2 Data Used in the City Scale Analysis

Table B-6 Monthly Water Supply (1980-1990) by Lanzhou Water Company

Month	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1980	2341.24	2348.97	1946.90		402.07	161	802540
Feb.	2010.02	2088.72	1692.43		396.29	175	806710
Mar.	2741.77	2364.50	1944.12		420.38	164	806710
Apr.	2583.22	2733.32	2306.85		426.47	171	826800
May	2811.47	2524.59	2060.10		444.49	176	813980
June	2913.16	3074.94	2619.59		455.35	177	816960
July	2296.55	2385.91	1913.91		472.00	181	840830
Aug.	2288.86	2244.30	1760.93		483.37	186	837830
Sept.	1989.08	2110.60	1644.80		465.80	184	847290
Oct.	1925.57	1931.38	1410.14		521.54	198	846840
Nov.	2328.45	2131.40	1720.14		411.26	161	841150
Dec.	2307.09	2180.69	1726.16		454.53	172	851070
1981	2200.29	2189.93	1725.18		464.75	176	851355
Feb.	2009.96	2052.95	1612.94		440.01	184	851635
Mar.	2809.29	2362.61	1912.11		450.50	171	851635
Apr.	2661.66	2760.96	2309.43		451.53	177	852035
May	2700.28	2302.50	1835.48		467.02	176	853576
June	3052.45	3083.19	2593.18		490.01	191	855098
July	2359.02	2470.83	1994.71		476.12	179	857708
Aug.	2281.49	2183.82	1658.75		525.07	197	861731
Sept	1831.46	1966.48	1470.51		495.97	192	862751
Oct.	1851.80	1729.71	1259.05		470.66	176	862951
Nov.	2132.40	2025.81	1534.69		491.12	189	864151
Dec.	2360.14	2228.99	1743.99		485.00	180	867051
1982	2174.94	2180.01	1701.38		478.63	176	875551
Feb.	1907.98	2105.19	1606.04		499.15	204	875823
Mar.	2331.10	2005.33	1539.78		465.55	171	876283
Apr.	1967.22	1991.56	1517.57		473.99	180	876723
May	2591.81	2379.45	1897.17		482.28	177	876923
June	2196.83	2412.59	1945.45		467.14	177	881469
July	1963.95	1874.38	1367.34		507.04	185	885391
Aug.	2102.94	1961.96	1454.04		507.92	184	888971
Sept	1890.40	2009.31	1511.09		498.22	186	892371
Oct.	1915.28	1768.71	1302.91		465.80	168	893445
Nov.	2272.31	2135.72	1654.62		481.10	178	901945
Dec.	2254.03	2269.50	1807.62		461.88	164	909328
1983	1968.33	1971.10	1507.14		463.96	164	913130
Feb.	1794.50	1899.44	1462.60		436.83	171	914060
Mar.	2367.89	1985.70	1517.85		467.85	165	914470
Apr.	2283.58	2538.21	2045.27		492.94	179	915480
May	2239.24	2030.36	1570.38		459.98	162	916600
June	2250.86	2215.09	1737.63		477.46	173	921170

to be continued

Month	(1)	(2)	(3)	(4)	(5)	(6)	(7)
July	2051.36	2028.28	1552.50		475.78	166	921400
Aug.	1886.00	1869.84	1378.48		491.36	171	922710
Sept.	2016.18	1939.09	1437.93		501.13	181	924280
Oct.	1912.30	1874.23	1386.09		488.14	169	928190
Nov.	1902.33	1870.85	1367.58		503.27	180	923210
Dec.	2120.49	1953.02	1439.86		513.16	177	933600
1984	2153.27	2088.48	1564.65		523.83	181	932443
Feb.	2024.75	2105.94	1577.94		528.00	195	933051
Mar.	2370.46	2073.67	1594.49		497.18	172	933071
Apr.	2200.11	2041.45	1527.94		513.51	183	932771
May	2789.25	2741.48	2217.63		523.85	181	934725
June	2647.56	2651.34	2118.89		532.45	189	937620
July	2049.19	2146.04	1632.80		513.24	178	930465
Aug.	2054.59	1946.59	1406.83		539.76	186	935159
Sept.	1930.45	2039.48	1480.02		559.46	199	938441
Oct.	1851.76	1764.68	1250.91		513.77	176	941647
Nov.	2438.31	2211.37	1678.76		532.61	187	950601
Dec.	2206.99	2208.64	1702.47		506.17	171	953996
1985	2041.65	2001.73	1486.43		515.30	174	955068
Feb.	2193.95	2126.04	1604.06		521.98	195	954847
Mar.	2133.42	2099.03	1623.68		475.35	161	954841
Apr.	2468.00	2368.71	1858.75		509.96	178	954734
May	2566.17	2491.24	1976.89		514.35	173	957806
June	2491.73	2437.22	1912.98		524.24	182	957668
July	2377.38	2283.25	1783.33		499.92	168	961572
Aug.	2231.39	2143.22	1605.15		538.07	186	963507
Sept.	1961.43	1887.25	1339.25		548.01	183	964755
Oct.	1770.45	1723.51	1202.64		520.87	174	966685
Nov.	2145.64	2053.50	1541.81		511.69	176	968682
Dec.	2278.45	2143.11	1698.73		444.38	147	971265
1986	2176.23	2108.50	1626.27	41.71	440.51	146	971385
Feb.	2272.87	2168.49	1720.43	37.67	410.38	136	971315
Mar.	2077.14	2041.46	1625.00	34.22	382.23	141	971155
Apr.	2581.66	2475.25	2041.61	37.82	395.82	131	972077
May	2536.08	2428.65	1978.86	38.92	410.86	141	973610
June	2612.51	2442.02	1972.50	89.85	379.67	126	974062
July	2106.06	1960.80	1475.73	93.40	391.67	133	978870
Aug.	2217.78	2133.87	1597.32	107.29	429.27	141	985169
Sept.	2554.51	2454.83	1936.05	106.16	412.62	134	985962
Oct.	2286.88	2265.86	1733.52	103.71	428.62	144	990404
Nov.	2537.32	2505.71	1971.49	104.53	429.68	138	998236
Dec.	2273.84	2242.48	1741.93	98.39	402.16	134	1004112
1987	2196.03	2194.31	1676.47	98.34	419.50	134	1010503
Feb.	2272.30	2267.54	1777.04	91.53	398.97	127	1010003
Mar.	2184.39	2188.17	1712.85	94.92	380.40	134	1010601
Apr.	2589.56	2566.03	2056.93	101.09	408.01	130	1013446
May	2736.96	2695.42	2204.78	92.39	398.25	131	1014586
June	2886.90	2705.12	2199.69	100.83	404.60	129	1014586
July	2887.05	2765.99	2240.95	104.33	420.71	137	1020631
Aug.	2572.69	2458.81	1913.61	118.79	426.41	135	1022549
Sept.	2611.13	2390.10	1904.57	100.07	385.46	121	1028573

to be continued

Month	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Oct.	2401.49	2291.44	1802.78	96.23	392.43	127	1029092
Nov.	2073.24	1864.03	1385.05	92.47	386.51	121	1033109
Dec.	2434.95	2265.11	1810.05	87.09	367.97	118	1038162
1988	2181.58	2126.32	1623.53	101.32	401.47	125	1040094
Feb.	2244.73	2110.14	1611.57	103.38	395.19	123	1039914
Mar.	2260.02	2273.07	1699.46	107.85	465.76	154	1039924
Apr.	2819.38	2744.84	2232.52	82.41	429.91	133	1045018
May	2888.04	2801.83	2272.00	111.64	418.19	133	1045118
June	2972.85	2897.18	2337.38	111.69	448.11	138	1048587
July	3218.63	3116.28	2543.60	115.63	457.55	145	1050534
Aug.	3213.26	3133.26	2554.34	124.15	454.77	139	1054319
Sept.	3037.76	2998.37	2049.52	124.83	464.02	141	1063012
Oct.	2489.72	2473.82	1920.35	115.88	437.59	137	1063221
Nov.	2352.48	2333.99	1778.72	109.64	445.63	135	1064303
Dec.	2394.51	2389.07	1844.90	110.96	433.21	136	1065146
1989	2265.79	2210.75	1644.60	118.10	448.05	135	1069121
Feb.	2281.50	2211.43	1658.65	110.72	442.06	133	1071231
Mar.	2049.97	2049.05	1515.70	106.58	426.77	142	1070731
Apr.	2592.58	2450.44	1898.64	113.65	438.15	132	1071181
May	2610.94	2537.84	1994.13	115.11	428.60	133	1071001
June	2971.68	2850.05	2293.12	117.97	438.96	132	1071431
July	3008.42	2914.74	2372.77	118.97	422.68	131	1071799
Aug.	2859.40	2851.21	2225.97	121.57	503.67	151	1074655
Sept.	2418.26	2329.62	1732.34	119.71	477.57	143	1076748
Oct.	1996.54	1970.83	1387.06	120.56	463.21	143	1076537
Nov.	2243.31	2154.05	1587.76	116.45	449.84	135	1076509
Dec.	2291.14	2272.21	1700.34	118.34	453.53	140	1078673
1990	2141.25	2064.53	1500.80	115.34	448.39	134	1078821
Feb.	2066.49	1999.20	1435.53	112.67	451.00	135	1078321
Mar.	2065.18	2006.45	1485.26	108.63	412.56	137	1078420
Apr.	2356.09	2259.51	1677.27	122.13	460.11	138	1076133
May	2209.00	2144.14	1563.45	119.13	461.56	143	1075655
June	2602.71	2503.58	1902.84	139.63	461.11	138	1075864
July	2200.41	2118.22	1508.47	141.29	468.48	145	1078297
Aug.	2361.04	2250.00	1634.96	155.17	459.87	137	1079173
Sept.	2916.63	2799.06	2083.41	211.54	505.11	151	1078325
Oct.	2923.74	2894.09	2252.58	116.15	525.36	162	1078533
Nov.	2619.88	2512.52	1912.47	108.18	491.87	146	1089859
Dec.	2283.48	2258.05	1686.49	104.69	466.87	143	1091740

Source: LWC, 1980-90.

Note: **(1)**: total water supplied, in ten-thousand cubic metres; **(2)**: total amount of water sold, in ten-thousand cubic metres; **(3)**: industrial water use, in ten-thousand cubic metres; **(4)**: commercial water use, in ten-thousand cubic metres; **(5)**: residential water use, in ten-thousand cubic metres; **(6)**: per capita daily water use, in litres per capita per day; **(7)**: number of population served, in people.

B.3 Data Used in Household Scale Analyses

Table B-7 Water Use and the Situation of the Households (Group I)

No.	Family Size (people)	Income (yuan/year)	Floor Space (m^2)	Water Use (m^3)	Electricity Use (kwh)
01	3	2233	55	22	329
02	5	3128	55	132	798
03	4	7048	55	79	380
04	3	7411	55	159	292
05	2	6735	55	116	1110
06	4	4560	55	74	470
07	4	6290	55	100	607
08	2	3736	55	73	298
09	2	6371	55	97	213
10	3	3632	55	27	159
11	4	3623	55	34	283
12	4	3734	55	37	439
13	6	3560	55	89	184
14	2	3540	55	42	220
15	2	2762	55	12	108
16	3	6903	55	41	508
17	3	6035	55	40	173
18	4	4217	55	86	256
19	3	9086	55	59	1053
20	3	3924	55	58	174
21	3	4966	55	50	157
22	1	6123	55	20	470
23	4	7005	55	105	340
24	3	3603	55	46	126
25	4	7066	55	61	559
26	4	7186	55	158	294
27	3	7198	55	35	228
28	3	3929	55	34	208
29	3	3888	55	41	327
30	2	7455	55	40	527

Note: Data on water used by 30 households in Xining city in 1990, obtained by investigation.

Table B-8 Water Use and the Situation of the Households (Group II)

No.	Age of Head	Family Size (people)	Income (yuan)	Floor Space (m^2)	Water Use (m^3)	Water Fee (yuan)
01	45	4	3579.84	48.94	48	9.60
02	62	5	2747.88	75.85	72	14.40
03	45	4	6333.96	58.29	48	9.60
04	58	4	3799.44	54.15	48	9.60
05	28	3	4687.20	32.84	36	7.20
06	42	5	5275.92	54.15	8	15.40
07	30	3	4718.28	48.94	36	7.20
08	58	3	10251.84	65.67	41	8.16
09	61	4	7050.00	75.85	33	6.60
10	28	4	5348.64	54.15	36	7.20
11	58	4	7298.64	68.20	21	4.20
12	65	3	9470.28	89.90	99	19.80
13	70	5	11860.68	89.90	28	5.60
14	57	3	6956.04	68.20	24	4.80
15	56	2	6207.36	68.20	30	6.00
16	60	2	3291.36	68.20	20	4.00
17	62	2	7557.24	68.20	6	1.20
18	52	2	6789.60	68.20	33	6.60
19	68	3	7419.72	68.20	36	7.20
20	69	3	6711.72	68.20	36	7.20
21	72	6	8947.32	68.20	126	25.20
22	65	5	6952.52	100.37	60	12.00
23	35	1	3082.44	41.81	12	2.40
24	53	3	6054.12	77.61	60	12.00
25	29	3	5162.16	37.09	24	4.80
26	62	2	3741.48	48.52	12	2.40
27	32	3	5203.92	37.09	18	3.60
28	38	4	6556.56	37.09	24	4.80
29	42	3	6962.76	53.25	18	3.60
30	28	2	2343.12	24.36	18	3.60

Note: Data on water used by another 30 households in Xining city in 1991, obtained by investigation.

APPENDIX C: SIMULATION RESULTS OBTAINED IN THE CASE STUDY

Table C-1 Residential Water Demand Forecasts for Lanzhou Urban Area (108 scenarios)

Scenarios	Year 2000 Total (10^4 m^3)	Year 2000 Per capita (lpd)	Year 2010 Total (10^4 m^3)	Year 2010 Per capita (lpd)	Year 2020 Total (10^4 m^3)	Year 2020 Per capita (lpd)
111111111	8467	148.6	11130	163.9	15190	187.9
121111111	8795	154.4	12020	177.0	17210	212.9
131111111	7959	139.7	9759	143.7	12070	149.3
112111111	8412	147.6	11050	162.8	15090	186.7
122111111	8741	153.4	11940	175.8	17110	211.7
132111111	7905	138.7	9680	142.5	11960	148.0
113111111	8427	147.9	11080	163.1	15120	187.0
123111111	8755	153.7	11960	176.1	17140	212.0
133111111	7919	139.0	9701	142.8	11990	148.3
111122111	9219	148.6	12650	163.9	17870	187.9
121122111	9577	154.4	13660	177.0	20240	212.9
131122111	8667	139.7	11090	143.7	14190	149.3
112122111	9160	147.6	12560	162.8	17740	186.7
122122111	9517	153.4	13570	175.8	20120	211.7
132122111	8607	138.7	11000	142.5	14070	148.0
113122111	9176	147.9	12580	163.1	17780	187.0
123122111	9533	153.7	13590	176.1	20150	212.0
133122111	8623	139.0	11020	142.8	14100	148.3
111133111	7664	148.6	9556	163.9	12490	187.9
121133111	7961	154.4	10320	177.0	14150	212.9
131133111	7204	139.7	8377	143.7	9918	149.3
112133111	7614	147.6	9487	162.8	12460	186.7
122133111	7911	153.4	10250	175.8	14060	211.7
132133111	7154	138.7	8308	142.5	9833	148.0
113133111	7627	147.9	9506	163.1	12430	187.0
123133111	7924	153.7	10270	176.1	14090	212.0
133133111	7168	139.0	8326	142.8	9856	148.3
111111211	8530	149.7	11050	162.6	14240	176.2
121111211	8890	156.0	11890	175.1	15790	195.3
131111211	7973	139.9	9740	143.4	11860	146.7
112111211	8475	148.7	10970	161.5	14140	174.9
122111211	8835	155.1	11810	173.9	15680	194.0
132111211	7918	139.0	9660	142.2	11750	145.4
113111211	8490	149.0	10990	161.8	14170	175.3
123111211	8849	155.3	11830	174.2	15710	194.4
133111211	7933	139.2	9682	142.5	11780	145.8
111122211	9288	149.7	12550	162.6	16750	176.2
121122211	9679	156.0	13510	175.1	18560	195.3
131122211	8682	139.9	11070	143.4	13940	146.7
112122211	9228	148.7	12460	161.5	16630	174.9

to be continued

Scenarios	Year 2000 Total (10^4 m^3)	Year 2000 Per capita (lpd)	Year 2010 Total (10^4 m^3)	Year 2010 Per capita (lpd)	Year 2020 Total (10^4 m^3)	Year 2020 Per capita (lpd)
122122211	9620	155.1	13420	173.9	18440	194.0
132122211	8622	139.0	10980	142.2	13820	145.4
113122211	9244	149.0	12490	161.8	16660	175.3
123122211	9636	155.3	13440	174.2	18480	194.4
133122211	8636	139.0	11000	142.5	13850	145.8
111133211	7720	149.7	9481	162.6	11710	176.2
121133211	8046	156.0	10210	175.1	12980	195.3
131133211	7217	139.9	8360	143.4	9746	146.7
112133211	7671	148.7	9412	161.5	11620	174.9
122133211	7996	155.1	10140	173.9	12890	194.0
132133211	7167	139.0	8291	142.2	9662	145.4
113133211	7684	149.0	9431	161.8	11650	175.3
123133211	8010	155.3	10160	174.2	12910	194.4
133133211	7180	139.0	8310	142.5	9684	145.8
211111211	**8315**	**144.4**	**10730**	**156.5**	**13790**	**169.1**
221111211	8652	150.3	11520	168.0	15230	186.7
231111211	7795	135.4	9509	138.7	11560	141.7
212111211	8258	143.4	10650	155.3	13680	167.8
222111211	8595	149.3	11440	166.8	15120	185.4
232111211	7737	134.4	9426	137.5	11450	140.4
213111211	8273	143.7	10670	155.6	13710	168.1
223111211	8610	149.5	11460	167.1	15150	185.8
233111211	7753	134.6	9448	137.8	11480	140.8
211122211	9049	144.4	12180	156.5	16200	169.1
221122211	9415	150.3	13080	168.0	17890	186.7
231122211	8482	135.4	10800	138.7	13580	141.7
212122211	8986	143.4	12090	155.3	16070	167.8
222122211	9352	149.3	12980	166.8	17770	185.4
232122211	8420	134.4	10700	137.5	13460	140.4
213122211	9003	143.7	12110	155.6	16110	168.1
223122211	9369	149.5	13010	167.1	17800	185.8
233122211	8436	134.6	10730	137.8	13490	140.8
211133211	7533	144.4	9222	156.5	11350	169.1
221133211	7838	150.3	9900	168.0	12540	186.7
231133211	7062	135.4	8172	138.7	9516	141.7
212133211	7481	143.4	9150	155.3	11260	167.8
222133211	7786	149.3	9828	166.8	12450	185.4
232133211	7010	134.4	8101	137.5	9428	140.4
213133211	7495	143.7	9169	155.6	11290	168.1
223133211	7800	149.5	9847	167.1	12470	185.8
233133211	7023	134.6	8120	137.8	9450	140.8
211111111	8257	143.4	10810	157.7	14680	179.9
221111111	8564	148.7	11640	169.8	16560	203.1
231111111	7782	135.1	9527	138.9	11750	144.1
212111111	8199	142.4	10730	156.5	14570	178.6
222111111	8507	147.7	11560	168.6	16460	201.8
232111111	7724	134.1	9444	137.7	11650	142.8
213111111	8215	142.7	10750	156.8	14600	179.0

to be continue

Scenarios	Year 2000 Total (10^4 m^3)	Year 2000 Per capita (lpd)	Year 2010 Total (10^4 m^3)	Year 2010 Per capita (lpd)	Year 2020 Total (10^4 m^3)	Year 2020 Per capita (lpd)
223111111	8522	148.0	11580	168.9	16480	202.1
233111111	7740	134.4	9466	138.0	11680	143.2
211122111	8985	143.4	12280	157.7	17240	179.9
221122111	9319	148.7	13220	169.8	19460	203.1
231122111	8468	135.1	10820	138.9	13810	144.1
212122111	8922	142.4	12180	156.5	17120	178.6
222122111	9257	147.7	13120	168.6	19330	201.8
232122111	8405	134.1	10720	137.7	13680	142.8
213122111	8939	142.7	12210	156.8	17150	179.0
223122111	9273	148.0	13150	168.9	19370	202.1
233122111	8422	134.4	10750	138.0	13720	143.2
211133111	7480	143.4	9292	157.7	12080	179.9
221133111	7758	148.7	10010	169.8	13640	203.1
231133111	7050	135.1	8188	138.9	9677	144.1
212133111	7428	142.4	9220	156.5	11990	178.6
222133111	7706	147.7	9934	168.6	13550	201.8
232133111	6998	134.1	8116	137.7	9589	142.8
213133111	7442	142.7	9239	156.8	12020	179.0
223133111	7720	148.0	9953	168.9	13570	202.1
233133111	7012	134.4	8135	138.0	9613	143.2

Note: The nine numbers used for describing each scenario stand for the alternative values adopted for the set of initial variables and the eight parameters respectively, following the order given in Table 11-1 and 11-2. "211111111", for example, means that the initial variables adopt the second set of the alternatives, and the eight parameters, from CPAI to AVSR, all adopt the first one of their alternative values as listed in Table 11-2.

Table C-2 Industrial Water Demand Forecasts for Lanzhou Urban Area (64 scenarios)

		Year 2000		Year 2010		Year 2020	
No.	Scenarios	Total (10^4 m^3)	Unit value (m^3/wy)*	Total (10^4 m^3)	Unit value (m^3/wy)	Total (10^4 m^3)	Unit value (m^3/wy)
01	11111111	33770	205.28	41680	147.71	46590	111.73
02	11112111	32900	200.00	40120	142.17	44320	106.29
03	11111211	34990	212.71	43790	155.16	49580	118.90
04	11111121	36410	221.33	48510	171.91	58670	140.70
05	11111112	33730	205.04	41610	147.43	46460	111.42
06	11112211	34120	207.43	42220	149.62	47310	113.46
07	11112121	35540	216.05	46950	166.37	56400	135.26
08	11112112	32860	199.76	40040	141.89	44200	105.98
09	11111221	37630	228.77	50620	179.36	61660	147.87
10	11111212	34950	212.47	43710	154.89	49450	118.59
11	11111122	36370	221.09	48430	171.63	58540	140.39
12	11112221	36770	223.48	49050	173.82	59390	142.43
13	11112122	35500	215.81	46870	166.09	56280	134.95
14	11112212	34080	207.19	42140	149.34	47190	113.15
15	11111222	37590	228.53	50540	179.09	61530	147.56
16	11112222	36730	223.24	48970	173.54	59270	142.12
17	21111111	33470	204.27	41900	148.20	47700	113.53
18	21112111	32640	199.21	40290	142.50	45110	107.36
19	21111211	34690	211.74	44000	155.63	50690	120.65
20	21111121	36110	220.39	48730	172.35	59780	142.28
21	21111112	33430	204.03	41820	147.92	47570	113.23
22	21112211	33860	206.68	42390	149.93	48100	114.48
23	21112121	35280	215.33	47120	166.65	57190	136.11
24	21112112	32600	198.97	40210	142.22	44980	107.06
25	21111221	37330	227.86	50830	179.79	62770	149.40
26	21111212	34650	211.50	43930	155.36	50560	120.34
27	21111122	36070	220.15	48650	172.07	59650	141.98
28	21112221	33760	206.06	42200	149.24	47780	113.73
29	21112122	35240	215.09	47040	166.37	57060	135.81
30	21112212	33820	206.44	42310	149.66	47970	114.18
31	21111222	37290	227.62	50750	179.51	62640	149.09
32	21112222	36460	222.56	49140	173.81	60050	142.93
33	21211111	31980	209.56	43660	145.62	62880	103.11
34	21212111	31150	204.13	42050	140.24	60290	98.86
35	21211211	33200	217.57	45770	152.63	65870	108.01
36	21211121	34390	225.37	50890	170.01	81220	133.17
37	21211112	31940	209.30	43580	145.36	62750	102.90
38	21212211	32370	212.14	44150	147.25	63280	103.76
39	21212121	33560	219.94	49370	164.64	78630	128.93
40	21212112	31110	203.87	41970	139.98	60160	98.65
41	21211221	35610	233.39	53080	177.02	84210	138.08
42	21211212	33160	217.31	45690	152.37	65740	107.80

to be continued

No.	Scenarios	Year 2000 Total (10^4 m^3)	Year 2000 Unit value (m^3/wy)*	Year 2010 Total (10^4 m^3)	Year 2010 Unit value (m^3/wy)	Year 2020 Total (10^4 m^3)	Year 2020 Unit value (m^3/wy)
43	21211122	34350	225.12	50900	169.75	81090	132.97
44	21212221	34790	227.96	51470	171.65	81620	133.83
45	21212122	33520	219.69	49290	164.35	78500	128.72
46	21212212	32330	211.88	44080	146.99	63150	103.55
47	21211222	35570	233.13	53000	176.76	84080	137.87
48	21212222	34750	227.70	51390	171.39	81490	133.62
49	11211111	32280	210.62	43440	145.15	61770	101.81
50	11212111	31410	204.95	41880	139.93	59510	98.08
51	11211211	33500	218.59	45550	152.18	64760	106.74
52	11211121	34690	226.36	50760	169.59	80110	132.04
53	11211112	32240	210.36	43370	144.89	61650	101.60
54	11212211	32630	212.92	43980	146.95	62500	103.00
55	11212121	33830	220.69	49200	164.37	77840	128.30
56	11212112	31370	204.69	41800	139.67	59380	97.87
57	11211221	35920	234.34	52860	176.62	83100	136.97
58	**11211212**	**33460**	**218.34**	**45470**	**151.92**	**64640**	**106.53**
59	11211122	34650	226.11	50680	169.33	79980	131.83
60	11212221	35050	228.67	51300	171.39	80830	133.23
61	11212122	33790	220.44	49120	164.11	77720	128.09
62	11212212	32600	212.67	43910	146.69	62370	102.79
63	11211222	35880	234.08	52780	176.36	82970	136.76
64	11212222	35010	228.41	51220	171.13	80770	133.02

Note 1: "m^3/wy" means cubic metres per ten-thousand yuan.

Note 2: The eight numbers used for describing the scenarios stand for the eight parameters, from AVCDR to AVPVR, listed in Table 11-5. There are no alternatives set for the initial variables and the other four parameters (AVCEE to AVPRR), so that they are not indicated by numbers.

Table C-3 Agricultural Water Demand Forecasts for Lanzhou Urban Area (36 scenarios)

No.	Scenarios	Year 2000 Total (10^4 m^3)	Year 2000 Unit area (m^3/mu)*	Year 2010 Total (10^4 m^3)	Year 2010 Unit area (m^3/mu)	Year 2020 Total (10^4 m^3)	Year 2020 Unit area (m^3/mu)
01	**A111**	**4126**	**336.82**	**3500**	**282.86**	**3056**	**244.53**
02	**D111**	**4739**	**386.82**	**4119**	**332.86**	**3681**	**294.53**
03	**H111**	**3697**	**301.82**	**3016**	**247.86**	**2619**	**209.53**
04	A211	4069	336.82	3417	282.86	2954	244.53
05	D211	4673	386.82	4021	332.86	3558	294.53
06	H211	3646	301.82	2994	247.86	2531	209.53
07	A311	4012	336.82	3336	282.86	2855	244.53
08	D311	4608	386.82	3926	332.86	3439	294.53
09	H311	3595	301.82	2923	247.86	2447	209.53
10	A112	3838	313.29	3168	256.07	2737	218.97
11	D112	4450	363.29	3787	306.07	3361	268.97
12	H112	3409	278.29	2735	221.07	2299	183.97
13	A212	3785	313.29	3093	256.07	2645	218.97
14	D212	4389	363.29	3697	306.07	3249	268.97
15	H212	3362	278.29	2671	221.07	2222	183.97
16	A312	3732	313.29	3020	256.07	2557	218.97
17	D312	4327	363.29	3610	306.07	3140	268.97
18	H312	3315	278.29	2607	221.07	2148	183.97
19	A121	4103	336.82	3466	282.86	3015	244.53
20	D121	4712	386.82	4079	332.86	3631	297.53
21	H121	3676	301.82	3037	247.86	2583	209.53
22	A221	4045	336.82	3383	282.86	2912	244.53
23	D221	4646	386.82	3981	332.86	3508	297.53
24	H221	3625	301.82	2964	247.86	2496	209.53
25	A321	3989	336.82	3302	282.86	2814	244.53
26	D321	4581	386.82	3886	332.86	3389	297.53
27	H321	3574	301.82	2893	247.86	2411	209.53
28	A122	3816	313.29	3138	256.07	2699	218.97
29	D122	4425	363.29	3750	306.07	3316	268.97
30	H122	3390	278.29	2709	221.07	2268	183.97
31	A222	3763	313.29	3063	256.07	2608	218.97
32	D222	4363	363.29	3661	306.07	3203	268.97
33	H222	3342	278.29	2644	221.07	2191	183.97
34	A322	3710	313.29	2989	256.07	2519	218.97
35	D322	4302	363.29	3573	306.07	3095	268.97
36	H322	3295	278.29	2581	221.07	2117	183.97

Note: The letter in describing the scenarios stands for the climatic situations, in which "A" for normal years, "D" for dry years, and "H" for humid years; the other three numbers stand for the alternative values issued for AVIAR, CWIAR, and AVECR, as listed in Table 11-8.

Table C-4 Commercial Water Demand Forecasts for Lanzhou Urban Area (24 scenarios)

		Year 2000		Year 2010		Year 2020	
No.	Scenarios	Total (10^4 m^3)	Per capita (lpd)	Total (10^4 m^3)	Per capita (lpd)	Total (10^4 m^3)	Per capita (lpd)
01	111111	2537	50.68	3981	64.41	5749	76.62
02	112111	2213	44.20	3150	50.96	4126	54.99
03	111221	3086	56.61	5062	72.08	7475	84.72
04	**112221**	**2692**	**49.38**	**4005**	**57.03**	**5365**	**60.80**
05	111331	2017	44.52	2987	56.31	4185	67.85
06	112331	1760	38.83	2364	44.55	3003	48.69
07	111112	2585	51.63	3926	63.52	5280	70.37
08	112112	2234	44.62	3128	50.61	3954	52.70
09	111222	3144	57.67	4992	69.93	6866	77.81
10	112222	2717	49.84	3978	56.63	5141	58.26
11	111332	2055	45.35	2946	55.53	3844	62.32
12	112332	1776	39.20	2347	44.24	2878	46.67
13	211112	3259	64.40	4945	79.23	6648	87.81
14	212112	2816	55.66	3940	63.13	4978	65.76
15	211222	3958	71.88	6278	88.60	8631	97.04
16	212222	3420	62.12	5002	70.60	6463	72.67
17	211332	2596	56.64	3719	69.35	4851	77.84
18	212332	2244	48.95	2963	55.25	3633	58.29
19	211111	3199	63.22	5014	80.35	7238	95.61
20	212111	2790	55.14	3967	63.57	5194	68.61
21	211211	3885	70.56	6366	89.85	9398	105.66
22	212221	3389	61.55	5037	71.09	6744	75.82
23	211311	2549	55.60	3772	70.32	5282	84.75
24	212331	2223	48.50	2984	55.64	3791	60.82

Note: The six numbers used in describing the scenarios stand for the set of initial variables and the five parameters, following the order as listed in Table 11-11 respectively.

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